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A TREATISE

ON

ELECTROMAGNETIC PHENOMENA

AND ON THE

COMPASS AND ITS DEVIATIONS ABOARD SHIP.

MATHEMATICAL, THEORETICAL, AND PRACTICAL.

BY

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VOL. I.

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FIRST THOUSAND.

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To My Wife:

A TRIBUTE
TO
THIRTY YEARS' COMPANIONSHIP
CHARACTERIZED BY
UNIFORM GENTLENESS AND AFFECTION,
STRICT TRUTH AND PRINCIPLE,
AND SOUND JUDGMENT.

SUBJECT-MATTER OF THE PARTS.*

PART FIRST: ELECTROMAGNETIC PHENOMENA.

PART SECOND: THE COMPASS.

PART THIRD: THE SHIP A MAGNET.

PART FOURTH: THE MATHEMATICAL THEORY OF THE DEVIATIONS.

PART FIFTH: SWINGING SHIP AND COMPENSATION OF THE DEVIATIONS.

PART SIXTH: VARIOUS MATTERS BEARING ON THE MAIN SUBJECT.

* Part First occupies this volume; the five other Parts will be in a second volume of similar size.

A list of the works studied, read, or consulted for writing this Treatise will be given after Part Sixth.

SYNOPSIS OF PART FIRST.

INTRODUCTION.

At the present time, Physicists speak of the ether of space and deal with its properties and movements with as much confidence in its reality as in the air we breathe; but outside of the circle of investigators into natural phenomena and those familiar with their results through reading, there is a large number to whom such matters wear a hazy aspect that is further mystified and often rendered unattractive by the very technical language of their treatment. Such language is the necessary and proper medium between scientific men, but for the layman to understand it requires a search through dreary pages of literature to the origin of its terms: this is disheartening, and deters many—even those to whom such information is necessary for matters with which they deal—from a knowledge of the generalizations of natural phenomena toward which the investigations of the present day are tending.

Part First of this Treatise is written with those in view who may use the five succeeding Parts—that is to say, to convey to them such information regarding the principal phenomena of magnetism in such manner as will afford an intelligent grasp of the subject. To this end, it is necessary to go beyond the restricted limits of magnetism itself.

and show how it is related to heat, light, electricity, and chemical action—all presumably due to ether-waves.

Not that every electromagnetic manifestation is explicable by wave motion only, any more than that one movement alone of air and water produces the divers results experienced in them. Air and water are at times perfectly calm and placid, but they still produce pressure; and so there is a permanent electric charge upon a body, and an equally immovable magnetic condition in a steel bar, but around both the ether is in a stressed state: air and water sweep along as a violent gale and turbid stream, and so in the ether there is something akin to this right-line movement in the electric current; air and water circle round and round as the cyclone and whirlpool, and so in the ether we find a rotary motion called magnetic; lastly, in air and water there are waves—a periodic rise and fall as indicated by the barometer within [illegible] and tide gauges in any harbor; and so whenever a magnet moves, there is a motion of the surrounding ether which becomes periodic—a veritable wave, if the motion of the magnet be rhythmic.

Now many motions of two of the related magnets treated [illegible] work—the Compass and the Ship—*are* rhythmic, [illegible] Earth, which influences both, is swept by periodic [illegible] known as the daily, monthly, yearly, and secular [illegible] of the magnetic elements—fluctuations [illegible] the tides of air and ocean.

[illegible] commotion of ether waves arising from these [illegible] Compass, Ship, and Earth constitutes the [illegible] phenomenon of most importance to the [illegible] treatise, but as it cannot be taken for granted [illegible] the waves in it exist, evidence is adduced

at the outset to establish both facts; and hence because of its importance as a physical feature in producing the effects to be investigated, as well as an analytical process known as Fourier's Theorem that forms the basis of the mathematical theory of the deviations, this wave-motion is treated with some detail.

Waves are liable to certain changes by reflection, refraction, polarization, absorption, and interference—and these are all briefly explained and illustrated. Some of these changes take place in air and water, and as they thus present the matter more clearly to the mind, they are dealt with in the beginning; then a step is made into the ether of space, where all the attributes of wave-motion are found: one—interference—is a peculiarity of wave-motion alone, and characterizes not only waves of visible fluids, but also the movements of the ether, and hence these movements are inferred to be waves.

As occasion arises throughout the book, the relationship of the several phenomena due to ether-waves is pointed out. The Compass, the Ship, and the Earth are but magnets of different size, whose mutual relations as the first guides the second over the waters of the third, forms the subject-matter of this Treatise.

When several magnets are brought within each other's influence, they create a complex magnetic field; and if suspended by silken threads attached to their centers of gravity, they will exhibit a diversity of movement—repulsion, attraction, and oscillation of varied degree. They are quick—nervous—slow—or sluggish—according to their size and the motion given any one of them.

And this is the condition of the Compass as the magnetic

poles of the Ship swing round and about it in her rolling, pitching, onward movement—a condition that is aggravated by the changing intensity of the Ship's magnetism itself, through shock of waves, and the ever-varying fields of terrestrial magnetism through which she passes. The Compass is never at rest, and points anywhere except to the magnetic north.

But, erring and errant, we must still use it to guide us in fog and through storm, in the darkness of night and over the waste of waters that has no landmark; only, we must know its deviations accurately and the means of reducing them to manageable limits.

In the compass-needle the poles are symmetrically situated with regard to a central cross-section, so that an equation is easily formed to delineate its field—the surrounding lines of force: but in the Ship and the Earth—the two magnets that affect the Compass—there is nothing regular; the lines of force for each are sinuous, warped, and wavy to a degree that might tax the skill of any mathematician to express them analytically.

Such distorted environment might seem to entangle the effects on the Compass; yet there are none of its errors that cannot be accurately determined.

Its deviations, the result of a surrounding magnetic field, —however made up,—belong to a class of phenomena that pervade all nature—*periodic motion.*

This is analytically expressed by Fourier's Theorem which is explained in Part Sixth, and the adaptation of its general terms to the special case of the deviations is given in Part Fourth. Even each component of the complex field is investigated—in the case of the Ship, the magnetic survey

described in Part Third fully shows the magnetic character of every vessel; and in the case of the Earth, its magnetic elements as indicated by lines of Intensity, Dip, and Variation are completely determined by Gauss' theory explained in Part First.

These examinations of Ship and Earth in connection with that of a steel magnet (a compass-needle) described in Part First, bring strikingly into view the fact already stated, that the Compass, the Ship, and the Earth are three magnets differing only in size: in each there are the two foci of intensity, one near each extremity, and a neutral zone between.

This identity of *kind* is most important to understand well, for it is the key to all their mutual relations.

The scope of usefulness of the Compass covers the Earth, and from this Earth comes its directive power—that magnetism which vitalizes an inert bar of steel, and makes of it a sensitive, moving body—quick to declare its affinities and antipathies.

The Compass, then, is not an isolated entity, but wherever it wanders it finds kindred of some degree: with the Ship it is always in close touch, while at the same time it feels the ever-varying throbs of universal magnetism. Considering the immense commerce carried in iron ships and the armed force of nations that patrols the sea in fleets of steel, it is hardly exalting it too much, to say that the little instrument that guides them is well worthy of every effort for its improvement and intelligent use.

The chief endeavor to explain magnetism has been in the direction of establishing it among the forms of energy that, under varying circumstances, becomes manifest as heat, light, electricity, and chemical action; and in doing this, advantage

has sometimes been taken of such analogous phenomena as occur in the solid, liquid, and gaseous states of matter, but only for illustration, and not at all because magnetism is considered *material* in its nature.

Though invisible, magnetism is a *real* force, capable of doing work of different kinds, just as a man or a horse does: it can move a light load or a heavy one—pull so many pounds with a definite velocity in a given direction. It is merely one phase of the many transformations of energy that we daily see, whose antecedent is always a push or a pull, whether mechanical or molecular. Consider the chain of motion that leads up to the traction of a street-car by electricity: vibration in the molecules of coal and oxygen whose chemical combination gives rise to heat in a boiler; oscillation of the piston of a steam-engine as a result of the heat; rotation of the armature of a dynamo in consequence of the piston's motion; the flow of a current in a wire and a magnetic wave in the surrounding medium caused by the dynamo's rotation; and finally, as the net result of all, the visible speeding of a heavy mass along a track! "No pullee, no pushee, go like hell alla same!" as the Chinaman said in San Francisco, when he saw a cable-car for the first time. He was mistaken: there were both pulls and pushes all along the line, and equally there are pulls and pushes in the series of actions that transforms the violent rush of atoms into the useful rate of speed of an electric car.

The idea of mechanical tension is that of a stretched rope—a weight hanging at one end, the other fastened to a beam; or, a rubber band pulled apart by the hands. If a weight be attached to each end of the band (placed on a

table), and the hands release their hold, the contractile force of the material will draw the weights toward each other.

So, with the ether of space: it is a medium connecting matter just like the rope or the rubber band; it is thrown into electromagnetic stress by every turn of the dynamo or other magnetic machine, and the alternate tension and relief therefrom will move a weight just as the rubber band does. Sometimes there is only a statical balancing of forces, as when a compass-needle rests in equilibrium at a certain angle—the deviation—between the magnetic stress of terrestrial magnetism and that of an iron ship; and again it is a dynamic action, as when a small horizontal needle is oscillated in site of the compass to determine the magnetic force. In both the static and dynamic cases the tension of delicate rubber threads might replace the magnetic tension and produce the same visible effects. In essence the mechanical and the magnetical tension are the same—each can move a certain weight through a definite distance or form a balance between opposing forces; and all this is susceptible of accurate measurement and expression in any units we please: the deviation becomes specific in angular measure and the horizontal force in dynes.

The rope will bear only a certain tension, beyond which it breaks; the rubber has a limit of elasticity, and, similarly, a load may be put upon magnetic stress that it cannot move. Thus magnetic phenomena, like the visible material work of life, comes naturally within the domain of mathematics.

The foregoing comparisons are made to render intelligible the application of symbolic formulæ to the principles of a phenomenon that at best has but a hazy form in our mind—not a definite image that one can see and feel—but an

intangible something that still has much of the mystery that the word magnetism itself suggests.

It is a subject not readily grasped, and therefore I have tried to bridge those gaps that often occur between formulæ in works of this kind, so that easy transition from equation to equation may leave the mind free for the main subject without wearisome stoppages to clear the way of mathematical briars or undergrowth.

The Treatise is divided into Six Parts, which are subdivided into Chapters, these again into Sections, and the latter into numbered Articles with head-lines indicative of their import. In each Part is grouped matter illustrative of one phase of the subject; in each Chapter a prominent feature is described; in the Sections the lineaments of this are traced; and in the numbered Articles the details are followed out: thus, every topic has the advantage of individual presentation.

The Articles are numbered consecutively from beginning to end of the Treatise; the Sections begin a new series of numbers with each Chapter; and the Chapters a new series with each Part. The Formulæ of each Chapter have serial numbers of their own, so that the number of the formula and that of the Article in which it occurs are necessary for definite reference: thus, (14)—122, refers to formula No. (14) in Art. No. 122.

In Part Sixth will be found a Table of Symbols that have the same signification throughout the work.

In some instances it has been found expedient to use the English-American system of weights and measures, and in others the French; while recognizing the incongruity of this procedure, it was deemed best to adopt it on account of the

familiarity of those who may use the book with the first rather than with the second system, avoiding ambiguity in every case by stating the system in which the measurements are expressed.

A complete list of the works consulted, read, or studied in preparation for this book is printed at the end, or after Part Sixth. I have especially to acknowledge the courteous permission of Messrs. D. Appleton & Co. and The Macmillan Company (of this city) to use some extracts and figures from their publications.

In the body of the work very few references are made to investigators whose labors afford the sum of reliable information that exists on the subjects treated: their writings are not always accessible to the majority of those for whom this Treatise is written, and hence not likely to be consulted by them; while those who might have recourse to original sources can readily judge of the verity or accuracy of the matter in the garb I have given it: therefore, for the former references were an encumbrance, and for the latter a superfluity. I have endeavored, however, to faithfully present the subject in accord with the generally accepted views upon it.

Throughout the subject run certain principles of mechanics and magnetism; they are the structural timbers which may be fashioned variously: instruments are constantly improving, observers assert their individuality in the manner of using them, and even methods of analytical treatment are not free from change—but the principles themselves are immutable, and these it has been my endeavor to make clear. Once understood, any variation of treatment by analysis or instruments becomes a matter of easy acquisition.

NEW YORK, March 25, 1901.

PART FIRST.

CHAPTER I.

A MEDIUM NECESSARY TO THE PRODUCTION OF MAGNETIC PHENOMENA.

Section One: The Earth's Atmosphere.

1. **The air a material substance.**—The Earth is enveloped in a mass of air whose reality is proven by many facts. It is a mobile body whose regular ebb and flow within the Tropics is indicated by the daily oscillations of the barometer; and whose swaying back and forth toward either Pole is shown by the system of Trade Winds following the Sun in its course from solstice to solstice. As the gentle breeze, it cools the summer heat, and in the hurricane it rends and destroys. The robin's trill, equally with the locomotive's shrill shriek, carve it into waves that fall upon the ear. The fleet wings of birds as well as the heavy sails of ships are spread to it for passage to distant climes.

We can compress the air and thus transmute our energy into its power to do work: we can rarify it to any degree, or exhaust it altogether from a closed vessel. A given volume of it can be accurately weighed; and its composition has been well determined—a mechanical mixture of certain gases. The height to which it extends in space is practically

known. It has been liquefied, thereby affording ocular and tangible proof of its materiality.

Thus, many facts establish the existence of the air as a material substance, although (as a gas) we can neither see nor feel it as we do solid substances.

2. **Air the medium of sound.**—Waves of air fall upon the ear, throw the auditory nerve into vibration, and this reaching the brain causes the sensation of sound. The origin of the sound may be the chirp of a cricket or the explosion of a bomb, but the series of condensations and rarefactions into which both cricket and bomb mould the air, will reach every ear within the limits of their energy and produce their distinctive effects. And the air is in perpetual motion from countless sources of sound: the hum and rumble of a city; the multitudinous noises of Nature in field and forest; the crashing of the storm; and the din and jar of machinery employed in the affairs of life. But deprive the Earth of its atmosphere, and all sound would cease, although ears were present to hear and the activity of life should continue unabated; what causes the change? The medium to transmit the motion from the source to the ear is wanting!

To cite an instance that has often been tried: an alarm clock is placed under a glass receiver, and suspended by a silken fibre so as to isolate it by the slenderest means from surrounding solid matter; when the clock begins to ring, the air pump is worked, gradually the ringing becomes fainter, until, when the receiver is entirely exhausted, no sound at all is heard, although the mechanism is still seen to be in movement. On slowly re admitting air, the tinkle of the bell returns, waxes stronger with more air, and attains its loudest note when the receiver is filled as at first.

3. **Phenomena that occur in space void of air.**—Although we could not hear in a vacuum, still, if life were possible without air, we could continue to see; experience various degrees of warmth or cold; produce certain chemical reac-

tions; use electricity in diverse ways; and attract or repel one magnet with another—all as well *in vacuo* as in air at normal pressure.

Experiment has established the following facts: that the more perfect the vacuum, the better will one electrified body *induce* a similar state in another body; and the more freely will one magnet respond to the movement of another; that an electrified glass rod will attract a pith-ball as well *in vacuo* as in air; that a vacuum facilitates photography—a chemical process; and that the enclosed space of a room is thrown into such condition by an alternator, that a small glass bulb *exhausted of air*, lights up of itself in the room without leading wires to any source of electricity, and that the greater the rate of alternation, the more nearly is the glow in the bulb to that much-sought achievement—light without a filament—the brilliance of the magnetic waves alone *in vacuo*.

The dark thermal rays from a source of heat have been projected into a glass vessel void of air and concentrated there by a lens upon a piece of charcoal raising it to white heat *in the vacuum;* more than this, air at a freezing temperature might be admitted to the vessel, and a piece of platinum could be all but fused by the obscure rays of heat brought to a focus upon it. The air acted no necessary part in any of these experiments, while in some it was an actual impediment.

Section Two: Magnetic Action in Particular.

4. Magnetic action in space void of air.—Connect two thin metal discs *D D*, Fig. 1, by a brass rod *R* and place on the floor a hoop *H* covered by a tense membrane strewn with fine, dry sand; then hold the rod vertically a foot or so above the membrane, and stroke it with a resinous rubber; instantly, the sand will jump into fantastic figures—the visible vibrations of the rod conveyed to the membrane by the lower

shivering disc and the air in the space *A:* so, a bar of wrought iron waved near an incandescent lamp causes it to fade, and a vacuum tube brought near an alternator lightens into a glow. In both cases the effects of magnetic waves become visible in space void of air: can it be conceived that absolutely empty space was made to glow in the one, or that it was the brightness of entire void that was dimmed in the other?

Again: Fig. 2 represents a glass receiver in connection with an air-pump; *M* is a delicately pivoted magnet, *C* a cop-

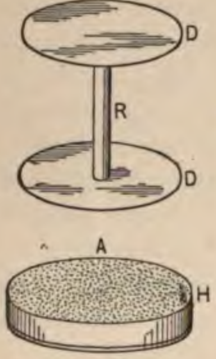


FIG. 1.

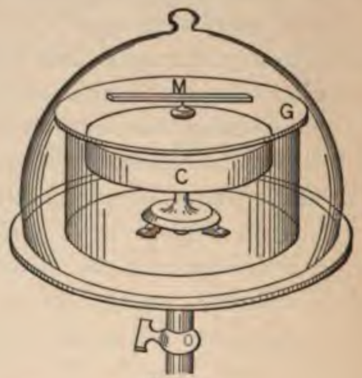


FIG. 2.

per disc poised on a pivot and susceptible of rapid rotary motion by any mechanical contrivance, and *G* is a plate of glass interposed as a screen between the magnet and disc. Exhaust the air from the receiver and spin the disc: soon the magnet will move too, and ere long it will follow the disc in its whirling; yet, quite a space void of air separated them. Not only this, but substitute thick slabs of wood, stone or ivory for the glass between the magnet and copper disc, and the rotation of the latter will still carry the magnet round. And if the magnet were first spun by mechanism, it would impart corresponding rotation to the copper disc: the action is reciprocal.

Consider the space between the poles of a powerful electro-magnet: stop the current, and the air offers no impedi ment to a hand-saw—it may be thrust across the line joining the poles—the air may be "sawed"—with the utmost ease; but start the current, and instantly a viscous medium seems to be evoked which requires great effort to saw through. And this resistance and its absence may be alternated as often as we start or stop the current.

Clearly, the air was not a factor in the condition, and equally clearly some other medium was.

5. Magnetic action through solids and over distances. —In the Smithsonian Institution, Prof. Henry found that "a single spark from the prime conductor of a machine, of about an inch long, thrown on to the end of a circuit of wire in an upper room, produced an induction sufficiently powerful to magnetize needles in a parallel circuit of iron placed in the cellar beneath, at a perpendicular distance of 30 feet, with two floors and ceilings, each 14 inches thick, intervening."

At the Magnetic Observatory on the grounds of the U. S. Naval Observatory, Washington, D. C., in 1897–8, the record of the vertical force instrument of the magnetograph was chiefly that of the potential or electric load upon the trolley line of the Tennalytown Road, and not that of the changes in terrestrial magnetism, although a distance of 1300 feet separates the magnetic instrument from the nearest point of the road.

The photographic record presents a fuzzy, tortured, irregular band during the working hours of the road, and this condition is greater or less from day to day according to the electric load on the line—much more exaggerated in summer and on busy days of travel than in winter; while at night, when the cars do not run, the line of terrestrial magnetic change is thin, clear, and regularly variable.

The vertical force instrument is a horizontal needle delicately poised by little trunnions on agate knife-edges,

veable in a vertical plane ac- the vertical component of the tion is automatically photo- well as the others of the same large bell glasses, *exhausted* a vault 15 feet or more below the magnetic waves from the reach these instruments, had to 300 feet of solid earth and then asses!

the Director of a magnetic ested against electric trolley cars tory than fifteen kilometres— the delicacy of the magnetic in- would be affected by the elec- fluctuations in the current sent

a space.—But to pass beyond these scope of magnetic action, let us large area covered by a storm as the air-wave advances or ound to every shift of wind chilliness or warmth; and hy- with more or less moisture. promptly, and in unison, indi- conditions.

of instruments—magnetic of a different kind, even of a dead calm.

the continents of Eu- when every needle was together, as if hundred arms and regularly or wildly has taken part in

this simultaneity of movement; for, coincidently with a flaming prominence rising from its disc followed by a spot on its surface, magnetic needles at places as remote from each other as London and the Rocky Mountains have been observed to shiver in erratic tremors. Such a fact, oft repeated, as will be seen later, points to a bond of union between Earth and Sun—a medium filling all space.

Section Three: A Medium Necessary to Transmit Energy; the Ether.

7. Energy defined and illustrated.—Energy is the power to do work: this is indicated even by the phrase in daily use, that a man has great energy or little energy—meaning his potential resources for work.

By work, the air is moulded into a state of undulation—this reaches the drum of the ear, or any other tense membrane, and throws it into vibration: sound results, and it is at the expense of energy. Thermal, luminous, electrical, magnetical, and chemical effects are also attained by the decay of energy, but what is the medium of transmission and how is this accomplished?

Now there are only two ways of transmitting energy: either by the bodily transfer of matter, or as an undulatory movement. A cannon-ball fired from a gun impresses upon the point of impact the energy of the powder that impelled it—this is the bodily transfer: the elasticity of the material composing a train of cars standing upon a track will convey the bump of an engine through them all to the last one, which alone starts off—this illustrates the undulatory transfer, the method of sound. Again: let a loaded gun be fired at a man's hand; he becomes conscious of it in three different ways: first, by the pain due to the bullet striking his flesh—this is the material transfer of part of the powder's

weighted to be level, and moveable in a vertic cording to the fluctuations of the vertical comp Earth's magnetism: this motion is automati graphed. The instrument as well as the others magnetograph are covered by large bell glass *of air*, and they are located in a vault 15 feet or the level of the ground. Thus the magnetic wa trolley of the electric road, to reach these instrun pass through a thickness of 1300 feet of solid ea span a vacuum in the bell glasses!

Even more: in the year 1900, the Director observatory in Germany protested against elec coming nearer the observatory than fifteen about eight miles!—because the delicacy of t struments was such that they would be affec tromagnetic waves that the fluctuations in out through earth and air.

6. Magnetic action in space.—But to restricted instances of the scope of magn picture what occurs over a large area co centre: barometers rise or fall as the air recedes: weather-vanes swing round to thermometers fluctuate with chilliness o [illegible] expand or contract with mor

The several instruments promptly, [illegible] the prevailing atmospheric conditi

Similarly do another set of ir [illegible]—tell of violent commotion of [illegible] the atmosphere at the stillness o

[illegible] storms have overspread [illegible] America at the same time. [illegible] as with a kind of frenzy— [illegible] Briareus reached ou [illegible] every one moved [illegible] was upon him. Even

to trace magnetic action, like that of light, to the Sun, and infer for both the same medium.

It is difficult to convey an idea of the ether of space; for, while such a medium, no doubt, exists, still we cannot prove it, as with air; nor can we determine by experiment a single one of its properties. It is a figment of the imagination and partakes of all the haziness of whatever exists only as a conception—something we can neither see, feel, weigh, compress, nor analyze—only speculate about.

The mathematician attributes to the ether properties necessary to the formation of equations expressing its energy; the physicist ascribes to it qualities essential to the explanation of facts he observes; the electrician meets conditions that require further hypotheses; still others do not accept fully any one of these conceptions; and some even reject the ether altogether.

Indeed it has been variously called a gas, a liquid, and a solid like a sensitive, tremulous jelly—an entity without pores or interstices, but particle joining particle in one continuous, homogeneous mass pervading the universe—a substance the like of which has no analogue in all nature. Such a conception does not appeal to our reason.

We must, on the contrary, evolve an image and endow it with features that bear some resemblance to what we behold, and at the same time help explain the phenomena of which we consider it the seat; and this is the best that can be done at present toward making the ether an entity.

Let the ether, then, be supposed of dual nature—" composed of two precisely opposite entities, which is suggested by the facts of electrolysis; by the absence of mechanical momentum in currents and magnets; and by the difficulty of otherwise conceiving a medium endowed with rigidity, which yet is perfectly fluid to masses of matter moving through it. With the hypothesis of doubleness of constitution, this last-mentioned difficulty disappears. The ether as

a whole may be perfectly fluid and allow bodies to pass through it without resistance, while its two components may be elastically attached together and may resist any force tending to separate them, as a solid would if it possessed the requisite rigidity. It is like the difference between passing one's hand through water, and chemically decomposing it; it is like the difference between waving a piece of canvas about and tearing it into its constituent threads." (Prof. O. J. Lodge.)

Let this ether fill all space, enveloping Earth, Sun, and Stars, and permeating even the pores of matter. Then, like the heaving sea or mobile atmosphere, it will be agitated by surgings of many kinds—waves arising from the varied motions of the atoms of matter embedded in it: for the propagation of these waves the ether must have elasticity and density, just as the air has those properties to convey sound. Since the velocity of light is exceedingly great, so must be the elasticity of the ether, with correspondingly small density.

As the velocity of sound differs with the elasticity and density of the body through which it passes, so does Light travel faster or slower in divers media; so, too, Electricity finds different substances variously pliable to its strain; and so, also, Magnetism permeates the metals with more or less ease: to account for this diversity of behavior of these several forms of energy in the different kinds of matter, the ether, in addition to uniformly pervading the pores, is supposed to be condensed about the atoms, clinging to them in a sort of concentrated atmosphere, the degree of density being the same for atoms of the same kind, but varying with the substance.

It is a matter of observation that when a magnet or an electrified body is brought into the midst of similarly conditioned bodies, or *one* of an assemblage of electrified bodies is moved, there is a disturbance of the electromagnetic quietude previously existing—the sensitive ether around

them quivers and trembles: dynamos and other electrical machines only set up like tremors or urge them as pulses to a distance; and if these pulses accumulate in one place, they are in deficit somewhere else.

As regards the apparently irreconcilable properties of the ether—fluidity and rigidity—consider another substance, water; in its liquid state it yields to the lightest tread, but crystallized as ice upon the river it sustains the tramp of armies: or again, molten iron—how easily it flows in sinuous stream round any mould, but when cooled to the rigidity of a solid, only the most violent effort will rend it.

Is it incredible, then, that there should be another medium which invisibly welds a mass of nails between the poles of an electromagnet into such solidity as to bear the weight of tons, and yet when the current stops the arch crumbles into a shower of pieces?

CHAPTER II.

VARIOUS MOVEMENTS OF THE ETHER OF SPACE CONSTITUTE RADIANT ENERGY.

Section One: The Sun.

9. **As the sun is a prolific source of the various forms of energy** treated in this work, it will conduce to a better understanding of the subject, if the generally accepted view of its constitution and the principal facts relating to it, be stated.

Heat, light, and chemical activity we know come from the Sun, but the electromagnetic form of energy has not such undisputed title to direct descent; indirectly, however—as offspring of the other three—the lineage is beyond question: and when one phase of the energy passes so easily into the other—a mere variation of wave-length—it can hardly be doubted that all emanate with characteristic individuality from the same source.

10. **Solar heights and velocities.**—Spectrum analysis has revealed the constituent matter of the Sun, and the slow motion of this matter observed in the field of the spectroscope has been interpreted (upon Doppler's principle) to mean actual velocities of incredible amount. Both Doppler's principle and that of the spectroscope are described in articles 59 and 65: it is only with their results that we are concerned here.

An object on the Sun, that from our terrestrial standpoint would measure ten seconds of arc, has an actual height of six thousand miles, and one minute of arc is equal to about 28,000 miles: one of the hydrogen prominences to be described hereafter was observed to have an arc value of 13′, equal to 350,000 miles, and it was thrust upward from the photosphere with the astounding velocity of two hundred miles a *second!*

Actual motions of a thousand miles an *hour* are not rare, and towering forms of writhing gas, thirty thousand miles in height, are often seen.

11. Distance, density, and mass of the sun.—The Sun occupies one focus of the Earth's elliptical orbit, so that its distance varies with the season: the mean distance is ninety-three million miles. Our knowledge of this depends upon the measurement of solar parallax—a quantity, therefore, of the very first importance: indeed, secondarily, what we know of the distances of the whole celestial host depends upon it. The most accurate value of this parallax is 8.8″; it is the angle formed at a point of the Sun by the directions in which two observers, one at each end of the Earth's radius as a base line, would see the point. The base line is quite accurately known, but the angle is small and most difficult to measure; and the least inaccuracy introduces enormous errors into the distance resulting from calculation on the data: hence the unreliability of the Sun's distance to within thousands of miles. Upon the value given above, however, several other matters relating to the Sun have been determined: its diameter, 865,000 miles; weight, 330,000 times that of the Earth; density, one-quarter that of our globe; and force of gravity, twenty-seven times that we experience; or, to state it otherwise, such is the immense bulk of matter in the Sun—its attracting mass, that a body would there fall 443 feet a second whereas it falls only sixteen feet a second on the Earth, and a man weighing here 150 lbs. would there weigh about two tons.

The Sun revolves on its axis once in 25¼ days; and the velocity of light is 186,000 miles a second.

12. **Aspect of the solar disc.**—Viewed through a telescope, the Sun presents quite a different aspect from the smooth brilliant orb seen by the naked eye: true, it is not like the Moon, rugged, with mountain range and valley deep, affording strong contrasts of light and shade; but appears like a field of whitish sand strewn with large dazzling rice grains; or like lumps of the pure white curd of milk floating in a turbid whey—a contrast of brilliance and dullness—a mottled surface, produced by small shining bodies disposed in patches, groups, and streaks over a sombre ground.

13. **Constituents of the Sun.**—So many of the terrestrial substances have been found (by the spectroscope) in the Sun —iron, tin, zinc, lead, copper, carbon, silver, nickel, silicon, etc.—that it has been well said that if the Earth were heated to the degree the Sun is, it would give a similar spectrum. But the matter of the Sun cannot exist in either the solid or liquid state, as with us. Every element has a "critical" temperature, above which it cannot be liquefied, however great the pressure, and the temperatures of the Sun so far transcend those at which all the elements may be converted into vapor, that it is incredible that these elements should exist in any other condition than vapor in the Sun. This inference is corroborated by the solar density: being only about one-quarter that of the Earth, the same substances constituting both must be in different conditions in each—lighter in one, heavier in the other—vapors in the Sun, solids in the Earth. The Sun is therefore most probably a whirling ball of varied metallic gases, and this view is borne out by spectrum analysis.

The matter of the Sun cannot of course be of the same temperature and consistency throughout: in the core the heat must be more intense than on the rim, where it has free radiation into space; and the excessive compression must

render the inner gases of the viscosity of tar as compared with the mobility of the outer hydrogen.

The Sun is considered made up of a series of concentric layers or shells of very irregular outline—the nucleus, photosphere, chromosphere, protuberences, and corona. The photosphere is the dazzling disc we see, composed of brilliant self-luminous clouds floating in tenuous gases, just as the clouds of Earth hang in our atmosphere; but while ours are of watery vapor midst a mixture of oxygen and nitrogen, those of the Sun are droplets of many metals condensed on the outer confines of the Sun and buoyed up by vapors of the same metals and others less condensable.

Between and above the metallic clouds, the metallic atmosphere exists and constitutes the reversing layer that absorbs the radiant waves from the brilliant cloud masses, and thus furrows the solar spectrum with dark lines. When the disc of the Sun—the photosphere—is hidden during a total eclipse, there still remains, as a border outside it, the reversing layer—the solar atmosphere of incandescent metallic gases: "As the Moon advances, making narrower and narrower, the remaining sickle of the solar disc, the dark lines of the spectrum for the most part remain sensibly unchanged, though becoming somewhat more intense.

"A few, however, begin to fade out, and some turn palely bright a minute or two before totality begins.

"But the moment the Sun is hidden, through the whole length of the spectrum, in the red, the green, and the violet, the bright lines flash out by hundreds and thousands almost startlingly; as suddenly as stars from a bursting rocket head, and as evanescent, for the whole thing is over within two or three seconds. The [reversing] layer seems to be something under a thousand miles in thickness and the Moon's motion covers it very quickly." (Prof. C. A. Young.) This action of the reversing layer on the light waves forms the basis of spectrum analysis and is explained in article 59.

The Sun revolves [...] [...] range of flame—scarlet velocity of light is 180,00[...] [...]—bending and waving

12. Aspect of the s[...] [...]mosphere whose depth scope, the Sun presen[...] smooth brilliant orb see[...] [...]osphere, like stupendous the Moon, rugged, w[...] [...] masses of highly heated affording strong con[...] [...]ers eruptive: some like like a field of whitish [...] scarlet clouds with grains; or like lump[...] [...], writhing, cyclonic, pre- in a turbid whey-[...] [...] commotion, as if they had mottled surface, pr[...] [...] of the Sun: and indeed in patches, groups, [...] [...] an inference, for it con-

13. Constituents [...] whereas the quiescent substances have bee[...] [...] almost exclusively that [...] iron, tin, zinc, le[...] [...] that it has be[...] [...] are varied and extreme, [...] the degree the [...] [...]ousand miles, while some [...] the matter o[...] [...] are few double or treble [...] liquid state, as [...] temperature, abov[...] [...] the brilliant streamers, great the pressure [...] broad spokes of a wheel— [...] and those [...] [...] light, so filmy, so ethereal, [...] vapor, that [...] [...] beyond the single fact that it [...] any othe[...] [...] of the spectrum: this indi- [...] is corrob[...] [...] an incandescent gas, lighter [...] quarter that [...] which has not yet been found [...] both m[...] [...] *coronium* has provisionally [...], heavier [...]

[...] The [...] [...] light.—By suitable instru- [...] ared me[...] [...] heat of the Sun have been [...] analysis. [...] of a Bessemer converter:

The matt[...] [...] and the heat eighty-seven [...] perature [...] light and heat of the molten [...] radiation in [...] [...] the heat, light, and color

of the photosphere to such extent that they decrease greatly from center to circumference: considering heat, white light and its components each 100 at the center, they fall off in regular gradients, until at the circumference they are as follows: violet, 13; blue, 16; green, 18; yellow, 25; red, 30; white, 37; and heat, 43.

In concentrating the heat of the Sun with a burning glass, we merely produce the *effect* of approaching the object in the focus of the glass to such proximity to the Sun that the latter appears of the same size as the *lens* does, viewed from its own focus. "The most powerful lens yet made thus virtually transports an object at its focus to within two hundred and fifty thousand miles of the solar surface, and in this focus the most refractory substances—platinum, fire-clay, and the diamond—are either instantly melted, or dissipated in vapor." (Prof. C. A. Young.)

15. Renewal of radiation.—The enormous quantity of heat radiated by the Sun must have a source of supply, otherwise a perceptible decrease would be observed during the age of man, which is not the case. It is known that all space is strewn with cosmic matter—fragmentary particles from the size of a meteor to that of a planet: the impact of matter upon matter gives rise to heat, and if only a hundredth part the mass of the Earth were hurled from its distance into the Sun annually, it would maintain its radiance at a constant. Astronomical reasons, however, render this improbable as the only or chief source of renewal. Another possible means of supply is the contraction of the Sun itself: "The same total amount of heat is produced when a body moves against a resistance which brings it to rest gradually as if it had fallen through the same distance freely and been suddenly stopped. If, then, the Sun does contract, heat is produced in enormous quantities, since the attracting force at the solar surface is twenty-seven times that on the Earth, and the mass is so immense" (Prof. Young); and it has been calculated that an

annual contraction of the Sun's diameter of about three hundred feet would compensate for its radiation. This process brings about heat in another way: the confined gases of the nucleus must periodically reach a limit of compression when an outburst must occur, and volumes of the molten matter are hurled outward as the eruptive prominences indicate: reaching the outer cold of space, this matter is condensed into a metallic rain which falls in sheets upon the photosphere, giving out heat both by the impact and the process of condensation. We have the analogous process on Earth, when ascending vapors gather into clouds, fall as rain, and renew the streams that are temporarily depleted by flow into the ocean. Heat is absorbed in evaporation and given out in condensation.

16. The Sun's motion in space.—The Sun is not absolutely fixed: "it *do* move"; and is driving through space toward a point in the constellation Lyra, at the rate of thirty-three miles a second, dragging with it the whole planetary system; thus, "the Earth, instead of describing a closed ellipse, of which the Sun occupies one of the foci, really moves on a sort of elliptical helix traced on a cylinder of which the axis is the path of the Sun through space." (Angot.)

17. The Sun a source of magnetic energy.—Iron is the home of magnetism, and a mass of it placed in the midst of a stream of electromagnetic waves gathers them in as a sponge does water. Of all the metals in the Sun, the lines of iron are by far the most numerous, more than two thousand of them furrowing the spectrum; and they are also the most intense, calcium alone excepted.

While experiment shows that at very high temperatures magnets temporarily lose their distinctive virtue—to acquire it again on return to the original heat—still this does not exclude the probability of the various processes in the Sun producing electromagnetic energy. Scarcely a mechanical

action on Earth but excites the electromagnetic condition, which by suitable means may be converted into a current that expires in a succession of sparks. To enumerate but the principal sources, take *Friction;* any two dissimilar metals rubbed together will cause the electric condition, and one has only to recall the number of frictional machines that have been constructed for its abundant supply, to appreciate the importance of this source; *Crushing* or *Grinding* of bodies, which is but a kind of intimate friction of their particles; *Pressure, Rending, Concussion, Disruption, Vibration*—all these give rise to the electromagnetic condition.

The minute droplets of the various metals in the Sun are forever grinding, clashing, and rubbing against each other, and, as a consequence of these actions, *vibrating* also, and all with a power—a violence—beside which the most intense processes of the same kind on Earth are but the puny motions of pigmies. Imagine, if possible, the thrust that would hurl a mass of gaseous droplets of copper, zinc, iron, tin, and silver to the height of a hundred thousand miles with the velocity of a hundred miles a second, as occurs when an eruptive prominence is shot out from the photosphere—the grinding and crushing together of the particles—the resulting vibratory movement of the atoms—and then think if these processes produce electromagnetic waves on Earth, what billows must come from the Sun! And it is a well-established fact that often, concurrently with these eruptions in the Sun, the magnetic needles on Earth shiver and oscillate as if struck by a succession of these very billows: at the same time auroras appear; now, auroral stratification and colors may be produced in miniature in a vacuum-tube by bringing it within the influence of electric discharges; so that, granting that electromagnetic waves result from solar outbursts, when they reach the rare regions of our atmosphere, they illumine them, and as a consequence we have

those brilliant auroras that cap the magnetic poles like huge candle-extinguishers.

Chemical action is another fruitful source of electricity, and the chemical *effects* of the Sun's rays are everywhere visible: is it not likely, then, that with the substances and processes that supply electricity on Earth existent also in the Sun, there should be, midst its fiery violence, combination and disruption of elements—both chemical actions—and as a consequence electromagnetic waves of solar size?

Section Two: Radiant Energy Variously Illustrated.

18. Ancient and modern views of radiant energy.— In the early efforts to explain natural phenomena, Light was attributed to luminous particles shot out from some source; Heat was an imponderable, Caloric, that wandered from one substance to another; Magnetism was a peculiar effluvium emitted by certain metals; Chemical Reaction was Phlogiston; and even unto our day, Electricity is spoken of as a fluid, decomposable into positive and negative parts.

During the 17th century these views began to be questioned, and others put forward—hesitatingly at first, but with growing strength as bolder thought grappled the subject. About the beginning of the 19th century the Undulatory Theory of Light and the Dynamical Theory of Heat were clearly stated, and firmly established by experiment; and to-day, few, if any, dispute them. Electricity, Magnetism, and Chemical Reaction have also been spoken of as the results of a motion of some medium: the undulatory theory has expanded, and voices in its favor, like ripples from various sources, have risen at many points, and are moving in harmony toward the same goal; and the indications are, that they will eventually coalesce into one wave to drown all doubt

of Radiant Energy being a varied movement of some medium.

19. Primary motions.—There are four primary motions—translatory, rotary, oscillatory, and vibratory; and all others are compounds of these. The first is rectilinear—a car moving along a track; the second, round an axis, like a top or fly-wheel; the third, a to-and-fro swinging of the whole mass of the body, like a pendulum; and the fourth, a periodic *change of form* of the object itself, as a tuning-fork, which sways back and forth, alternating its form to a curved outline on each side of a straight line which is its middle position; or a vibrating bell, which changes from an ellipse in one direction to another at right angles thereto, while passing through its natural circular form between both.

The wave, or undulatory movement is made up of the translatory and oscillatory, and a combination of translation and rotation gives the spiral motion. Atoms, equally with large masses, may have any of the primary motions or their compounds; in masses they are called mechanical—in atoms, molecular; and this is the only distinction, that one is visible, the other not—there is no difference in kind in the motion of mass or molecule. An atom may rotate as the Earth does, or be projected in space as that body is; also it may vibrate as a bell and swing to and fro like a pendulum: all these unseen molecular motions are no less real than the visible mechanical movements of bell, car, or fly-wheel, and they have been reasonably inferred from varied experiment.

20. All substances reducible to definite elements whose atoms are forever vibrating.—Chemical analysis has reduced all matter to about seventy different elements, and spectrum analysis has established the fact that each of these, when in a state of glowing vapor, exhibits a distinctive color or group of colors by which it may be recognized.

A particular color is due to a specific wave of ether, and

each color being producible at will by raising its corresponding substance, in gaseous form, to a state of incandescence, it follows, both that the atoms of those vapors are the origin of the waves, and that, as these differ one from another, so do their sources.

The existence of waves requires motion in the source—a *vibration*—just as a rubber ball expanding and contracting in water will give rise to a motion in liquid.

From the myriad sources of light throughout the universe, ether-waves are circling forth: they commingle, cross, and interfere in every possible way; separately, they give color—combined, they give white light; as the simple undulation, they produce ordinary light—as the spiral wave, rotary polarized light: but whatever their effects, their origin is a vibration of atoms.

Ere the filament of a glow-lamp reaches the luminous stage, it has been warmed by the electric current: cover the bulb with the hand and we can feel its heat—how did it acquire it? Not from the current directly, for that did not enter the glass. It passed through the carbon only and threw its atoms into greater vibration: this excited waves in the ether, which fell upon the glass and urged its atoms into synchronous movement: the hand felt the latter by material contact, but it might have felt it also from concussion of the ether waves themselves. And mark, that these ether-waves arose in the center of the glass bulb and expanded across its enclosing space—a region void of air.

All matter is variously warm or cold to the touch, and is ever interchanging this condition with other matter in the vicinity; which is the equivalent of saying that the atoms of every substance in nature are variously vibrating, and hence sending out into the ether a multiplicity of waves of every conceivable amplitude, for upon this feature of the wave does the degree of heat depend.

Different substances are differently elastic and dense, and

as masses are only aggregations of atoms, it is reasonable to infer that the atoms are elastic and dense too, even variously so.

Elastic bodies—bells, tuning-forks, and piano-wires—have not one simple vibration alone; but upon the fundamental note is superposed a variety of harmonics coming from minor vibrations of the same body: so we may be sure that the elastic atoms of any one substance do not expand and contract in one single rythm, but like their aggregate masses, have their atomic overtones due to varied molecular movement.

21. Analogies of sound and light.—If we strike a golden plaque, it gives out a clear ringing note; if a brass plate, a harsh metallic clang; and if a sheet of lead, only a dull thud: it is the atoms of these metals in the aggregate that really take up the motion of the blow and pass it on as pulses of air; it is the same air that is the medium for all, so that the difference in sound must be due to the difference in vibration of atoms of gold, brass, and lead; each emits its distinctive note—a wave of specific length, period, and amplitude. Similarly, the atoms of elements in the Sun, glowing with the intensity of their motion, send out into the ether, waves equally characteristic of each element—waves of specific length, period, and amplitude.

The voice may be pitched to a deep base or high soprano; musical instruments yield both graver and shriller notes; and the possibilities of hearing are still beyond these: yet both above and below these limits there are sounds we cannot hear—the means of making them exist, but not one of the three thousand strings in the harp of the ear will respond. So with the waves of ether: they act upon the retina within certain well-determined limits of length and number per second, but for more or less we have no responsive fibres in the eye.

Pitch, or rapidity of vibration, is to sound what color is

to light; and for the diatonic scale in air there is the chromatic scale in ether—the musical notes of one have their analogues in the varied colors of the other: moreover, as from the violin we may draw notes the most grave to the most acute in one unbroken gradient, so do colors blend one into another without gap—a continuous variation in the number and amplitude of vibrations per second producing in their respective media—air and ether—notes from bass to soprano and colors from red to violet. And as the audible notes are flanked by others too grave and too acute for the ear, so on each side of the visible rays there are others in continuous series that do not affect the eye, but do produce heat, chemical activity, electricity, and magnetism.

The slaking of quick-lime—a chemical process—gives rise to a hissing sound, and the explosion of fulminates is another illustration of sound produced by chemical action; the crackling noise of a torrent of sparks from a statical machine is evidence of sound arising from electrical sources; the make and break of the current in an electromagnet may be done often enough to convert the click following each into a continuous hum, showing that sound can be caused by magnetism, the singing flame—a musical sound, is the direct offspring of heat; and by timing the reflection and withholding of a beam of light from a suitably prepared delicate surface the latter is thrown into such periodic motion that it gives a note corresponding to the frequency of the [illegible] and thus we have sound from light: if progeny de[illegible] much of its parent, then Sound—a movement of the [illegible] all these forms of radiant energy—points to them [illegible] of the ether. Motion in the Consequent—[illegible] presupposes motion as the nature or characteristic [illegible] heat, light, electricity, magnetism, and

[illegible] no conflict of these varied phenomena: the [illegible] heat field and the magnetic field of an atom are

two distinct spheres of influence in the same locality, just as light and sound occupy the same space.

22. Stress in the ether an electro-magnetic condition. —An electric car passing near a magnetic observatory gives every needle in it a shudder; the variation of the current in the conducting wire sends out a magnetic wave whose impulse all the instruments feel: so the surging of electro-magnetic billows on the Sun send violent tremors through magnetic needles on the Earth. With very rapid alternators, the current is neither wholly nor in great part a transfer of energy *in* a wire; it is only skin-deep and a very thin skin at that; it is mostly the transfer of a series of strains through the ether in immediate contact with the wire.

The ether around a charged Leyden jar, a dynamo, or other reservoir or source of electricity in operation, is in a state of strain—polarized, as it is called: it is energy in a condition of stress—the energy of the motive power that charged the jar or turned the dynamo; and the decay of this energy—the relief from tension of the ether—may be slow as in glass, or rapid as in copper, when it constitutes the electric current. In the latter case the decay is constantly and rapidly replaced—the tension renewed by the source; and the ether transmits the motions of the source as it receives them.

23. A platinum wire heated more and more displays all the prismatic colors in succession.—Here may fitly be described an experiment that has been variously performed: it will illustrate the intimacy between the different forms of radiant energy. In a darkened room stretch a platinum wire horizontally and have a foot or so of it of very small size. Connect the wire with a source of electricity outside the room; and have at hand a rock-salt prism, which gives the freest passage to heat rays, a battery, a galvanometer with spot-of-light pointer, a magnetic needle poised on a pivot, and a bolometer. This last is a "sensitive-nerve" to heat:

it consists of two small strips of iron or palladium placed in a little case, and its principle is the varying resistance these offer to an electric current when differently heated; and *so* sensitive is it that the difference in heat coming from a bright band and a dark line of the spectrum is indicated by the variation in current passing through it, and hence by a corresponding movement of the spot of light of the galvanometer with which the " nerve " is connected.

At first, all is dark in the room, and only by touch can we know that the wire is present; but send a weak current through it, and other indications of its presence arise: a gentle warmth emanates from its midst and a magnetic whirl surrounds it—the magnetic needle reveals the one, pointing everywhere across the direction of the wire, and a thermometer the other, whose rays, moreover, may be refracted by the prism. Increase the current, and the coexistent fields of heat and magnetism grow in intensity, while more refrangible rays pass through the prism. Urge the current more, and a faint red band will appear upon the wall, the first visible radiation to be refracted.

Continue to strengthen the current, and at each increase, a new and more refrangible band of color will be added to the preceding—orange, yellow, green, blue, indigo, and violet, each in its natural order, and eventually the final stage —white light.

While the more refrangible rays were successively emitted from the wire, those previously generated, persisted in their original wave-lengths, though each increased in amplitude—they became more intense, the obscure radiations warmer, the visual ones more vivid in color. The commingling of all the latter produced the white light that finally appeared.

By gradually lessening the current, the reverse of the foregoing takes place: violet first vanishes, then the others in order, eventually red, and lastly the fields of heat and mag-

netism disappear, and the presence of the wire becomes known only as at first by mere material contact.

24. Decomposition of white light.—The converse of the preceding experiment—the analysis of white light—will now be described. In Fig. 3 let *P* be a prism set up in a darkened room, and through a small hole in the wall at *R* let a ray of sunlight enter. If the prism were not there, the ray would continue directly to *K* as a pencil of white light; but passing through the prism (of different density from the air)

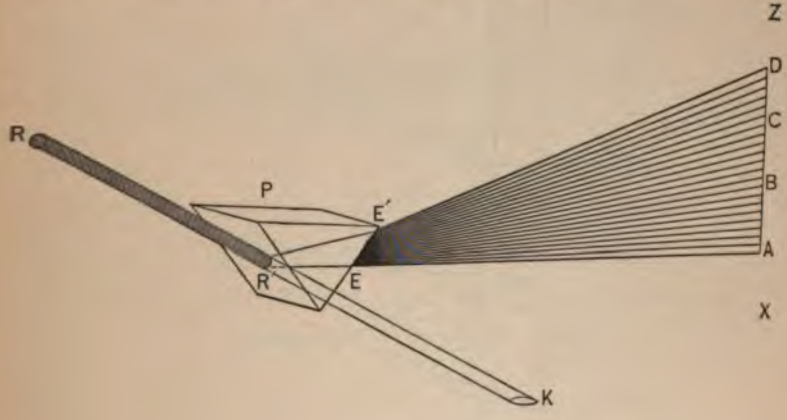


FIG. 3.

the velocity is thereby changed, and the light issues in a fan-shaped colored band, showing that it was not composed of rays of one refrangibility, but of waves of varied length, each variously retarded by the prism and thus differently bent out of the direct course. The group of colored rays between *B* and *C* is usually called the Solar Spectrum; but the complete spectrum embraces also the group of rays between *A* and *B* as well as that between *C* and *D*, both obscure, and which differ, *as waves*, from the middle luminous sheaf, only in that the former group consists of longer and less refrangible waves, and the latter of shorter and more refrangible ones.

The three groups produce different characteristic effects. Begin at X and pass the bolometer along the line $ABCD$ to Z, noting the galvanometer indications at regular short intervals—these indications are proportionate to the temperatures. Draw a line $A'B'C'D'$, Fig. 4, three times the length of $ABCD$ (merely to have a large and clear figure) and at A' erect a perpendicular to $A'D'$ proportional to the first re-

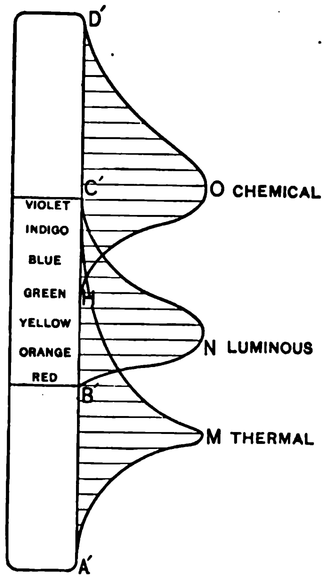


FIG. 4.

corded temperature above that of the room, *supposed constant*. Similarly, draw lines at all the intervals and make them proportional to the series of observed temperatures. Connect the ends of the lines and we have the thermal curve $A'MC'$ enclosing the region of waves that produce heat chiefly. It will be seen that from B' to C' they are mingled with the luminous waves, but that the maximum of heat does not come from amidst this mixture but well below it, and that, furthermore, above C' heat waves are rare.

To determine the relative brightness of the colors, a sim-

ilar procedure is followed with a photometer, one form of which is shown in Fig. 5. It consists of a telescope *os* set at right angles to a tube *T*; on the tube a lamp *L* is

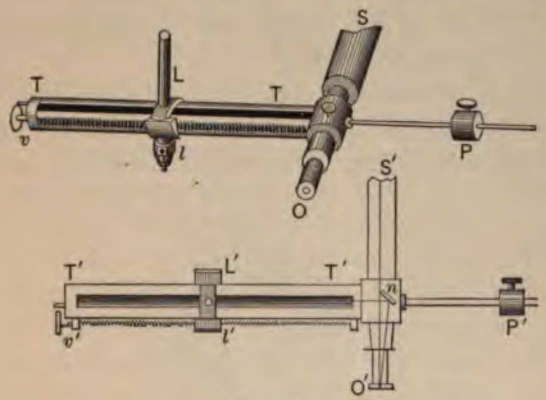


FIG. 5.

placed, which gives a steady light; it is moveable in and out by a micrometer screw *v*; *P* is a counterpoise, and below the figure is a section of everything with accented letters; a small mirror, *n*, is fixed at an angle of 45° with the axis of the telescope to reflect light from the lamp into the eye.

To make an observation, the telescope is directed to a color of the spectrum at a fixed distance from the edge of the prism, *P*, Fig. 3; the colored light enters the eye directly above the edge of the mirror, and that from the lamp by reflection from the mirror which occupies the lower half of the telescope; the lamp is then moved by the screw, *v*, until the edge of the mirror, which separates the two lights, no longer appears as a distinct line, and the intensity of both is then judged equal. The instrument is moved along the line, *ABCD*, of Fig. 3, and a similar observation made in each color. The *relative* intensities of the colors are inversely proportional to the squares of the several distances of the lamp from the mirror, for it had to be moved in each case to blend

the color with the light from the lamp, and these distances were given by the micrometer screw. Erecting perpendiculars along $B'C'$ proportional to these intensities, and connecting their ends, we have the curve $B'NC'$, to denote the relative brightness of the colors; and it will be seen that in the yellow is the maximum.

An entirely analogous method is adopted to ascertain the chemical efficacy of the different rays, employing an instrument shown in Fig. 6, called an actinometer. It consists

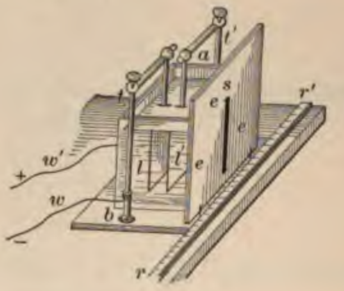


FIG. 6.

of a glass trough, *ab*, nearly full of water slightly acidulated to aid electric conduction; two metal columns, *t t'*, have arms from which hang two silver plates, *l l'*, dipping into the water; the plates are coated with a substance highly sensitive to chemical action; two wires, *w w'*, lead from the pillars to a very delicate galvanometer; three sides of the trough are opaque, the fourth clear and shaded by a screen, *e*, with a slit *s*; the apparatus may be moved along a graduated rule, *rr'*, and is used in a darkened room. A ray of sunlight is admitted as before, and passed through a vertical prism to obtain a horizontal spectrum for convenience of observation. This spectrum is first shaded off and the actinometer put in place so as to be moved along the line of the spectrum, *BC*, Fig. 3, for instance, supposed horizontal, and then beyond the visible rays, along *CD*. The slit is temporarily covered.

To make an observation, the screen is removed, the slit uncovered, and the swing of the galvanometer needle noted; for, instantly that the rays of the spectrum coming from the prism fall on the exposed plate, *l'*, the sensitive film suffers chemical decomposition, and this, like the similar process of a zinc-copper cell, which is also a chemical reaction, produces an electric current that flows through the wires to the galvanometer. The angle of deviation represents the efficacy of the rays in the position of the actinometer, for the strength of the current and consequent greater or less swing of the needle depends on the degree of chemical action caused in that part of the film by the light falling upon it. The slit is covered again, the instrument moved to a new position, and the procedure repeated. The several deviations and their corresponding locations along the spectrum afford the data for tracing the curve *HOD'* of the chemical rays in the same way that it has been done for the thermal and the luminous rays. It will be seen that while all three groups of rays overlap one another from *H* to *C'*, still their maximum effects are widely separated, and that that of chemical action is in the violet and ultra-violet region.

By the dynamical theory of heat the atoms of matter are in a state of vibration, varying in degree with its temperature and state, whether solid, liquid, or gaseous; so that the molecules of the substance coating the plates are considered as being in a vibratory condition. Among the waves of light falling on the plate, there are some which synchronise in movement with the vibratory motion of the molecules of the film, and these receiving the impact of the waves, like well-timed impulses to a swing, fly beyond each other's grasp and form new combinations: the motion as light has been taken up by the atoms with concentrated intensity and the result is a chemical reaction.

But this atomic rending and clashing are so many jars to the ether, and being regular and rapid, they constitute a

new kind of motion which is passed on to the galvanometer and moves its needle: this is the electromagnetic wave—a compound motion in the ether—alternate stress and its decay along the wire and a rotary movement around it.

Thus the movement called Light has been followed still as a movement of the ether in two other phases—chemical action and an electromagnetic current.

. The relation between Heat, Light, and Chemical Action is evident from the solar spectrum; they are all the effect of waves commingled and travelling together; the electric wave is the direct offspring of chemical action, and wherever electricity is coursing in a wire, there also is the magnetic whirl.

25. **Ether waves and their effects on matter.**—Ether-waves is the name given to the movements in the ether itself. As sound is a sensation of the brain due to waves of air beating upon the ear, so, ether-waves falling upon matter, produce, as it were, a sensation in its molecules; and the result takes the name of Heat, Light, Electricity, Magnetism, or Chemical Reaction, chiefly according to the kind of matter that the waves fall upon.

The energy as a wave has been spent as a manifestation in matter. A motion in the medium—ether-waves; a sensible effect in matter—heat, light, electricity, magnetism, or chemical reaction: this is the condition as well as the distinction.

There are not particular ether-waves for each class of phenomena—one set peculiar to heat, another to light, and so on; but the same waves falling on one kind of matter will be dissipated in it as heat, falling on another they become manifest as light, while in a third they set up a chemical reaction: not that the same train of waves will produce all these effects, nor some of them equally well, for they will not; certain waves will be strong in one effect and feeble in another, and they will produce some of the effects, and not others.

The Sun's rays give vigor to the trees of the forest: in time, they fall and form beds of carbon; this generates steam which moves an engine that actuates a dynamo, giving glow to an electric lamp, and thus the cycle of the sunbeam is a return into itself—Light! And throughout all these transformations, motion of matter and movement of ether may be traced as the actuating springs.

CHAPTER III.

WAVE-MOTION AND ITS PHENOMENA.

Section One: Waves in Different States of Matter.

26. A physical wave.—Wave-motion has both a physical and a mathematical representative, and each is important in the present subject; the first, because by means of it the kinship of the several forms of radiant energy will be more solidly established in Chapter IV of Part First, and the second, because it enables us to unravel the entanglement of the subject proper of this treatise—the Deviations of the Compass, and see clearly into their import.

The physical aspect of wave-motion will be dealt with in the present chapter—its mathematical, in Parts Fourth and Fifth: each is complementary of the other, and both fully illustrate the phenomenon.

The typical wave is the long swell of the sea during, or following, a gale.

It is of irregular outline, because the force that gives rise to it is fitful—the wind. And to indicate further the variability of this cause, two, three, or more waves of nearly the same size succeed each other, and then will follow a huge one, evidently raised by a series of heavy gusts—the varied impulses of the air impressed upon the mobile features of the sea: and we shall find the analogue of all this in wave-motion everywhere, as well as in the deviations of the compass—irregularity of final result due to the superposition of several causes, each symmetrical in itself.

27. A wave in solid matter.—In Fig. 7, *a b c* represents a long rubber tube hanging by its upper end; on taking hold of the lower end, stretching the tube a little, and repeating this act at certain short regular intervals, the tube may be

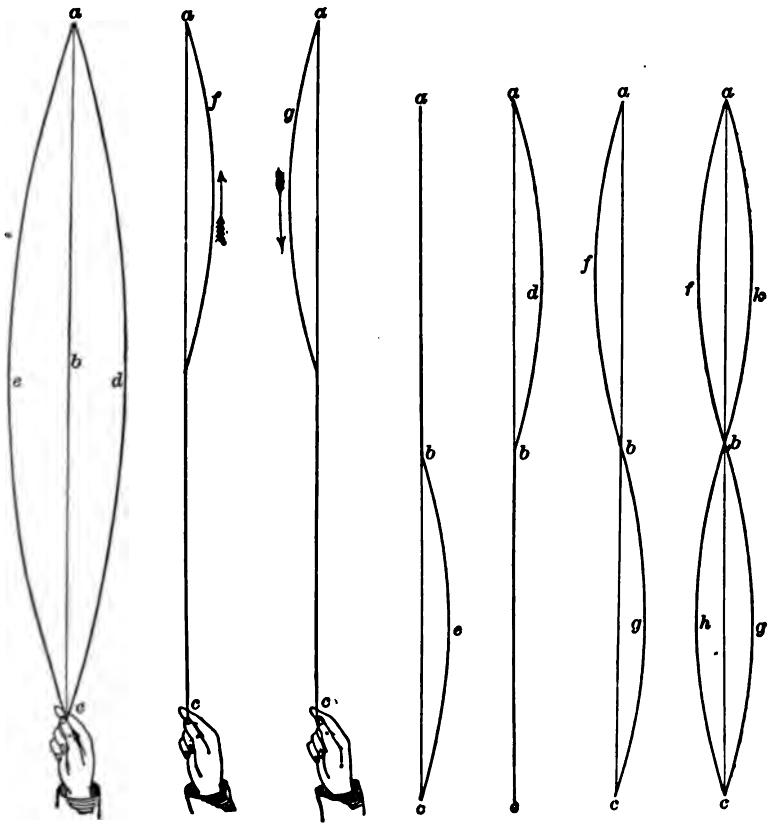


FIG. 7. FIG. 8. FIG. 9. FIG. 10. FIG. 11. FIG. 12. FIG. 13.

made to swing as a whole between *a d c* and *a e c*. It has a definite period of vibration, dependent on its length, weight, tension, and thickness, and the intervals of successive stretching must be identical with this period. While the tube is hanging quiet, if it be taken by the lower end and quickly jerked aside, a hump will be raised which will travel up its

length a little out of the vertical, say on the right side, and on reaching the fixed point *a*, will be reflected and travel down on the left side by the same amount from the vertical that it had gone up: in other words, the angle of incidence and of reflection of the hump at *a* are equal, and these respective positions are shown in Figs. 8 and 9. The time required for the hump to make the up and down trip is the period of vibration of this particular tube as a whole, and indeed it is the accumulation of such humps by repeated stretching that makes the tube swing to and fro as shown in Fig. 7. Now let the time necessary for this hump to pass from *c* to *a* be one second; at the end of half a second it occupies the position *c e b*, Fig. 10, its foremost end having reached the middle point; at the end of the full second, it occupies the position *b d a*, Fig. 11, its foremost end having reached *a*, the fixed point of the tube. At this instant, when reflection begins at *a*, and the pulse starts down to form the curve *a f b*, Fig. 12, let another jerk be given the end *c*; the resulting pulse will ascend, and after the lapse of half a second it will form the curve *c g b*, Fig. 12, its foremost end meeting at *b* the downward pulse, then fully formed in the curve *a f b*, since both pulses travelled in opposite directions with the same velocity. The hump *c g b* has the impetus to go [illegible] it must draw the point *b* to the right; the hump [illegible] has an equal impetus to come [illegible] to the left: these equal and opposite [illegible] immovable, so that it [illegible] were a fixed point, at which each pulse is re[illegible] Fig. 13, and *c g b* as *b h c* of [illegible] of the tube will vibrate [illegible] of each other, and so [illegible] pulses, the one direct from [illegible] meeting at *b*, we [illegible] Fig. 13. The [illegible] segments, [illegible] node.

If the jerks had been so timed as to cause the length of the hump to be one-third, one-fourth, or any other equal part of the tube, there would be along its extent at the same time three, four, or a corresponding number of vibrating segments separated by fixed nodes. In Fig. 12 the whole contour *afbgc*, from *a* to *c*, is called a wave; and to form it, the particles of the tube moved in succession to the right and to the left, while the direction in which this motion (or the wave) was propagated, was up and down; and this cross-motion of the particles is called transverse vibration. To illustrate it further, let Fig. 14 represent a row of small ivory

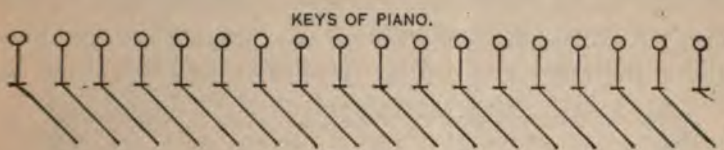


FIG. 14.

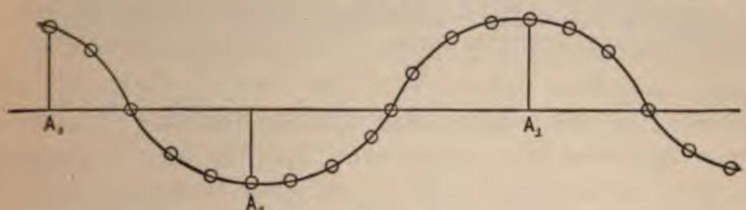


FIG. 15.

FIG. 16.

balls connected with any mechanism, such as the key-board of a piano, that will give them vertical motion: by running the fingers along the keys with varying pressure the balls may be successively raised and lowered, as in Fig. 15; draw-

ing Fig. 16 to follow this contour, we have the wave. The up-and-down motion of the balls, that is, the transverse vibration of the particles, is across the direction in which the wave travels, that is, the movement of the fingers along the keys.

28. A wave in liquid matter.—A wave in water is produced exactly like one in the rubber tube *ac*, Fig. 12. Let Fig. 17 represent a long narrow glass trough half filled with water. By quickly tilting one end upward, the water is given an impulse that, like the hump on the tube, is carried along the surface to the other end where reflection takes place. By continuing the tilting at suitable intervals, two stationary undulations with a node between may be formed; and furthermore, by shortening the interval of tilting, a succession of furrows and ridges, as in Fig. 17, may be produced—an un-

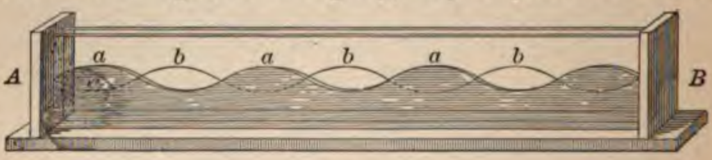


FIG. 17.

dulation that will begin at *A*, follow the line *aaa* to *B*, there suffer reflection, and return along the line *bbb*; or, more correctly speaking, there will be one series of outward-bound pulses and another series inward-bound, both series originating and ending at the nodal points where reflection takes place. In water, too, the vibration of the particle is transverse to the line of propagation of the wave. Whoever has seen the heavy seas roll in on the coast of Patagonia from the broad expanse of the Pacific, must have observed how placidly the albatross rides them—the bird is not swept along by their violence, but merely sinks from crest to trough and easily rises again as the billow passes beneath it. To be sure, the water has some onward movement in these waves, but practically the motion is one of alternate elevation and depression.

29. A wave in gaseous matter.—In atmospheric waves the particles of air vibrate longitudinally, or in the direction in which the wave is travelling. Let Fig. 18 represent a tun-

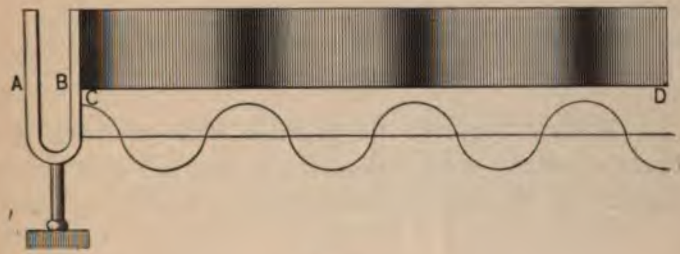


FIG. 18.

ing-fork: when set vibrating, suppose the first spring of the prongs to be outward—from each other; then a thin slice of air immediately outside prong *B* will be compressed, and this pressure will be communicated to the next thin slice, whereby the first slice becomes rarefied, and this condition will be further increased by the prong springing back toward *A*. A second outward and inward swing of the prong only adds to the effect, and continued vibration eventually results

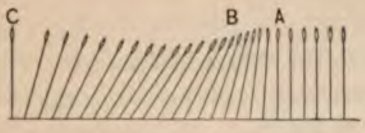


FIG. 19.

in producing an alternation of condensation and rarefaction along the line *CD*; the first is shown by the heavy shading, the second by the faint lines, and as light and shade merge gradually one into another, the condition may be represented by a sinuous curve, as shown; the condensations being all above a middle line, or normal state of the air, and the rarefactions below. Longitudinal vibration finds its illustration in the field of waving grain, where the heads, as in Fig. 19,

are successively grouped closely together, or widely separated; and this condition is brought about by the stalks moving to and fro in the line in which the wave-motion itself is travelling.

Section Two: The Genesis of a Wave, its Specifications, and Change of Symmetry.

30. **Energy required to produce wave-motion.**—From a center of sound, spherical waves spread out into space, as shown in Fig. 20, and the wave-front is defined by the con-

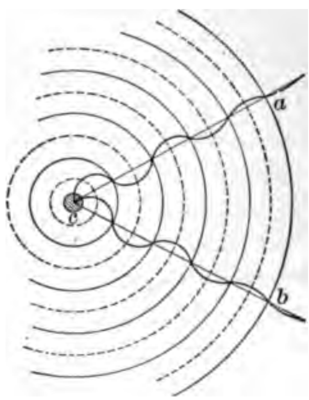


FIG. 20.

centric shells of air successively set in motion. Let a rubber ball at *c* be alternately compressed and expanded; it will correspondingly rarefy and condense the air outside it, which condition is passed on through the mass—fainter and fainter until the friction of the particles has wasted the energy in the medium which was imparted to it by the act of squeezing the ball. Thus it requires energy to cause the waves—the muscular exertion of pressing the ball, just as in the case of jerking the tube—of tilting the trough—of bending the tuning-fork. And the same is true of waves of ether: energy creates them, and on they travel, as radiant energy, until spent by friction of the medium, or decay in matter.

In all that precedes, the movement of the particle—its short excursion to and fro—is one thing, and the propagation of this motion throughout the medium is quite another. The first is the condition of the molecule of solid matter oscillating under the force of elasticity, or the drop of water rising and falling in the ripple, or the atom of air approaching and receding in the sound-wave, or the mote of ether vibrating in some manner; while the second constitutes the velocity of the resulting motion throughout the medium: in the case of air, it is the velocity of sound; in ether, that of light; and in water it is the speed with which the ripple expands into ever-widening circles.

31. Exact specifications of a wave.—Wave-motion is of universal occurrence in earth, air, and water: it is represented by a sinuous curve; and as the phenomena of nature are countless, so are the curves that stand for them. But all waves, whatever the medium in which they occur, or the physical fact they typify, have three features, and only three—length, form, and amplitude: these may be varied singly or together to produce an endless variety of outline.

The complete oscillation of a particle, whether transverse or longitudinal, is the distance it covers from starting, to its return to the same point—the round trip; and the time occupied in making it is called the Period of Oscillation: this period is also the time that a wave takes to advance a distance equal to its own length, so that Wave-length and Period of Oscillation have come to be regarded as synonyms, although the only ground for this is the fact that both extend over their respective spaces in the same time.

The oscillation of the particle will be further illustrated as follows:

In Fig. 21, let p be a pendulum-bob—an oscillating particle. When let go from a, it will swing to c and return to a again: this double journey over the arc ac is the *Oscillation*, and the *time* required to perform it, is the *Period*.

The motion may be represented by a wave. The vertical height through which the bob descends is *ef*; looking at it from a point *r* to the right in the plane *cef*, the successive positions of the bob in its fall to *b* will be *un*equal for *equal* inter-

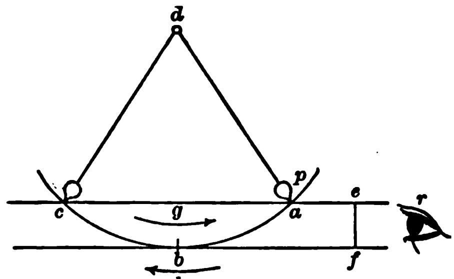


FIG. 21.

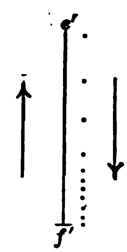


FIG. 22.

vals of time; this is shown by dots in Fig. 22, where the height is magnified: they are open out at first, then crowded together. In Fig. 23 *a'c'* corresponds to *ac* in Fig. 21; divide

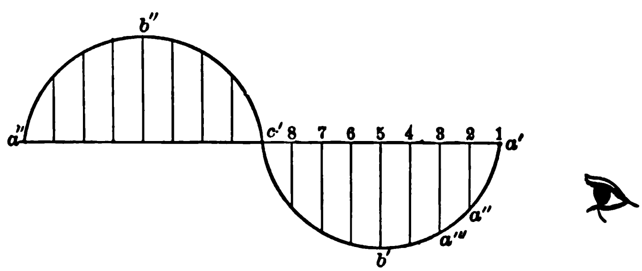


FIG. 23.

it into equal intervals, 1, 2, 3, etc., and drop perpendiculars from it proportional to the vertical fall of the bob at their respective intervals; each position of *a'* will successively be *a''*, *a'''*, etc., until it reaches the lowest point *b*, when we have *b'*, and then symmetrical positions on the other side to *c'* as the bob rises to *c*. This process repeated for the return of the bob from *c* to *a*, affords a similar series of perpendiculars *c'* to *a''*. Joining the ends of all these lines by a curve it is seen to be a wave, and its full length from *a'* to *a''* has been

described while the particle *p* made the circuit, Fig. 21, from *a* to *c* and back to *a*. This motion is typical of the particle of air, performing its little excursion while a condensation

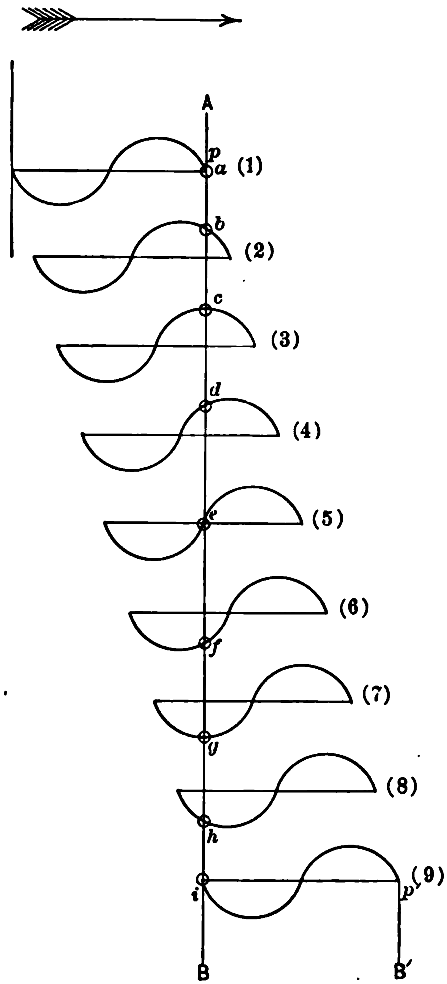


FIG. 24.

and rarefaction advance the distance of their united length; and of the molecule of rubber jerked to its elastic limit while

the hump climbs up one round of the tube; and in fact of every oscillating atom of matter, whatever the substance. Fig. 24 represents successive positions of a wave of water, each advanced $\frac{1}{8}$ of its own length, so that while (1) is the wave when it begins to move from left to right, (9) is its position when it has passed over a distance equal to its own length, or the point *p* of the wave, originally in the vertical line *AB*, has advanced to *B′*. Meanwhile, the drop of water *a* has gradually risen to *b* in (2), then to the upper limit of its oscillation at *c* in (3), next has fallen to *d* in (4), then to *e* in (5), to *f* in (6), and reaches the lower limit of its oscillation at *g* in (7), thence it ascends to *h* in (8), and finally attains its original level at *i* in (9); thus having completed one *Oscillation*—up-down-up—in the same *Period* that the wave advanced through its own *Length*. These several positions of the drop are shown in Figs. 25 and 26, where the letters cor-

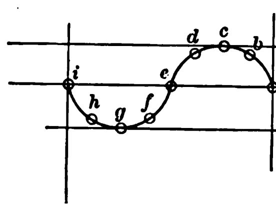


FIG. 25.

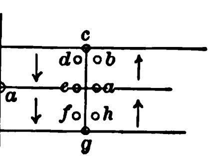


FIG. 26.

respond with those in Fig. 24. Successive drops go through a similar rise and fall, and thus the progress of the wave-motion continues.

In Fig. 27 let *HH* be the natural level of the water when

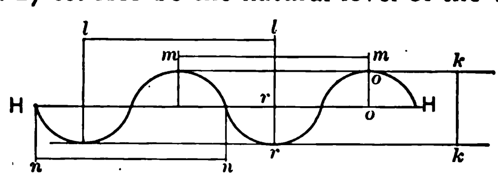


FIG. 27.

smooth: then the *Wave-length* is the distance from the highest point of one crest to that of the next, as *mm*, or from low-

e trough to that of the next, as *ll*, or the dis- any other two similarly situated points; the e extent of Oscillation of the particle, as *oo* ıich is equal to *kk*, or the vertical distance be- ı Figs. 25 and 26.

that change the symmetry of wave-outline. ·ving the same amplitude, *ab*, Fig. 28, the

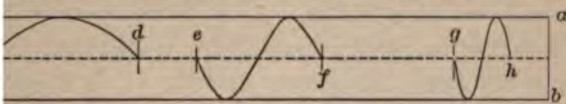
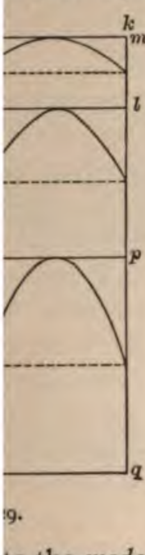
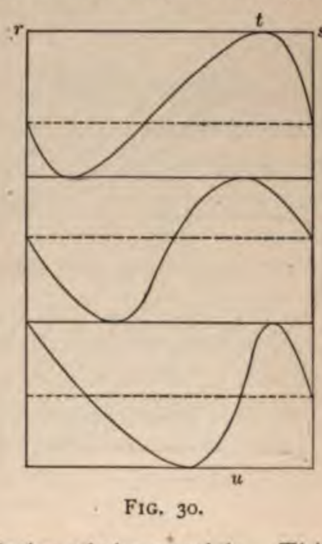


FIG. 28.

varied as *cd*, *ef*, *gh*, and thus have long and r, keeping the length *ik* constant, Fig. 29, the be varied as *lm*, *no*, *pq* and so represent high ɔr, finally retaining the same length and ampli- *rs* and *tu*, Fig. 30, the *form* may be changed





ɪ9. FIG. 30.

te the *mode of oscillation* of the particle. This ıown by Figs. 31, 32, 33. In these, the wave is ft to right, and the curved lines in each figure

represent successive positions of the front of one ridge; *AB* is the line of sea-level separating ridges from furrows (latter not shown); *d* is a drop on this level which the forward point of the wave encounters; the wave-point advances to e^1 and the drop is raised vertically to d^1; the wave-point reaches e^2 and the drop is lifted to d^2; and so on, as the wave continues to advance, the drop rises, until eventually, when the wave-point reaches e^{10}, the drop is at its summit d^{10}; but the rate of ascent or *mode of oscillation* in all three forms of the wave has not been the same: in Fig. 31, it is rapid at first, then steadily decreases; in Fig. 32, it is slow at first, then rapid,

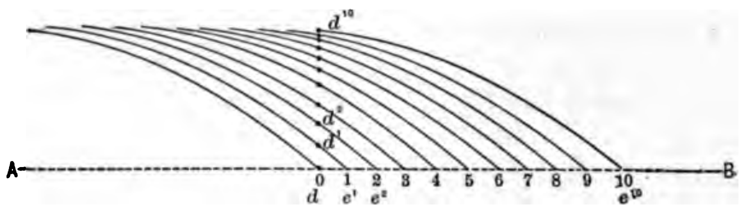


FIG. 31.

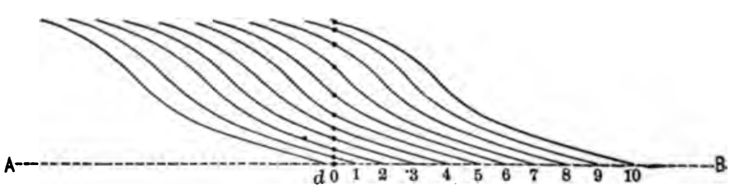


FIG. 32.

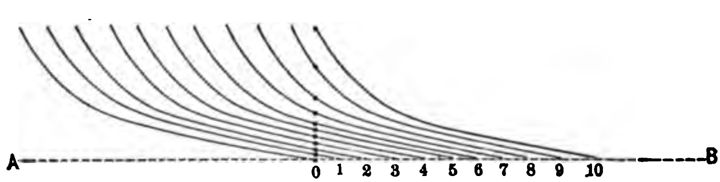


FIG. 33.

and again slow; while in Fig. 33 it is very slow at first and very rapid toward the end.

The length and amplitude of the wave are the same in all

three figures, so that their different form is due to the manner in which the drop oscillates between crest and trough.

The wave represented is not symmetrical, for in regular waves the rate of oscillation of the particle varies uniformly and is inversely proportional to the corresponding wave-length. This will be understood by Fig. 34, where waves of

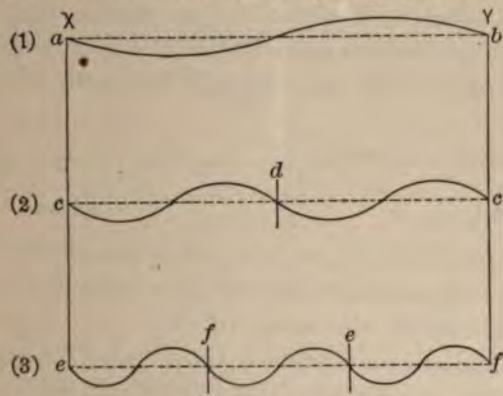


FIG. 34.

three different lengths are drawn; the first, *ab*, is as long as two of the second, *cd*, and three of the third, *ef*. As previously shown, a drop in *ab* makes one oscillation while the wave advances its own length *XY*; a drop in *cd* makes one oscillation in *its* own wave-length, *cd*, or two oscillations in the two wave-lengths covering *XY*; and similarly a drop in *ef* makes three oscillations in the three wave-lengths that equal *XY*.

The time that the waves are passing over the distance *XY* is supposed the same for all; therefore, in this time, a drop in *cd* makes two oscillations and one in *ef* three, while a drop in *ab* makes but one, or the rates of oscillation in *ab*, *cd*, and *ef*, are proportional to the numbers 1, 2, 3—inversely as the wave-lengths.

But a drop of water may receive the impulse of two waves at the same time, and these waves may meet the drop in divers ways, and hence cause a resultant *un*symmetrical wave.

represent successive positions of the fr
is the line of sea-level separating ridg
not shown); *d* is a drop on this level
of the wave encounters; the wave-p
the drop is raised vertically to d^1;
and the drop is lifted to d^2; and so
to advance, the drop rises, until e
point reaches e^{10}, the drop is at its
of ascent or *mode of oscillation* in
has not been the same: in Fig.
steadily decreases; in Fig. 32, i

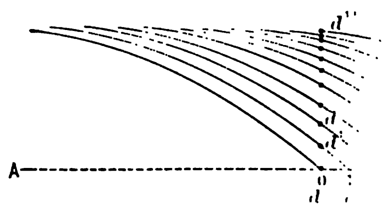
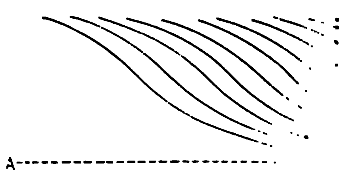
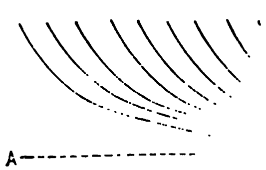


Fig.





and again slow;
very rapid towar
The length a

If struck one after the other, the two series of waves are separated by a corresponding interval; and they are then said to be in different phase. The curves *abc* and *def* illustrating three distinct differences of phase are shown in Figs. 41,

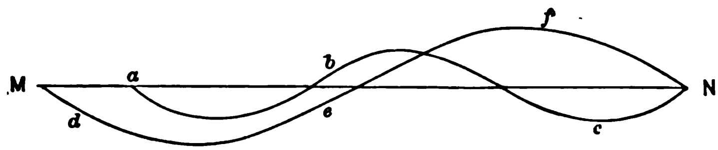


FIG. 41.

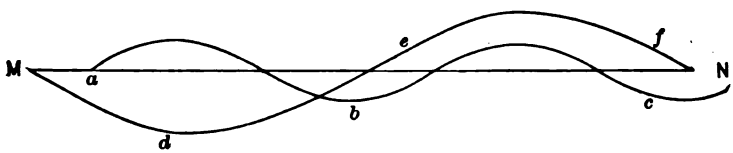


FIG. 42.

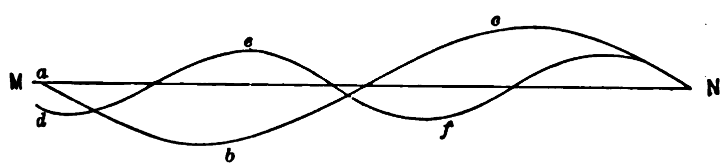


FIG. 43.

42, and 43: the curve resulting from their combination, in each figure, may be drawn by taking the algebraic sum of the ordinates on each side of the line *MN* and tracing a line through the ends of the resulting ordinates.

34. Analogy between wave-motion and that of a pendulum. — The matter of phase is of such importance in explaining the form of curves resulting from the combination of other curves, that it deserves further illustration: it will help to understand such odd contours as are sometimes found in curves of compass deviations.

There is exact similitude between the oscillation of a pendulum and the progress of a wave through water. Consider Figs. 44 and 45 together: the pendulum starts from a stop—the wave from sea-level; one attains maximum velocity—the

other extreme height; both velocity and height decrease as gradually as they grew, until, once more—for an instant—the pendulum is at a stop and the wave at sea-level; then the former returns just as it advanced, and the latter descends

FIG. 44.

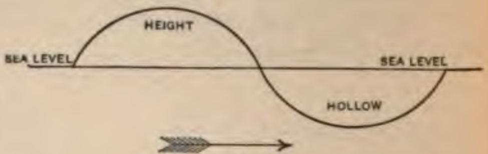


FIG. 45.

into a hollow the very counterpart of its height; the pendulum again comes to a stop and so the wave reaches sea-level: and thus, alternate motion and stop—height and level—until friction puts an end to both.

35. Varied compounding of two forces illustrative of phase.—In Fig. 46 let P be a pendulum fitted with a camel's-hair brush at e, and on a horizontal table beneath it, let a board (represented vertically at $FGHD$, Fig. 47) be covered with fine powder and placed so as to be swept by the brush.

When the pendulum is drawn to A and let go, it will swing to an equal height B, then back to A, and so—to and fro—tracing in the powder a straight line $a'C'b'$, Fig. 47: it has made one-quarter of an oscillation at c', one-half at b', three-quarters at c' on return, and a complete oscillation on reaching a' again.

At C' a definite force is acting on the pendulum—that of gravity due to the fall from the height of A to the level of C; let a blow equal to the force of gravity be given the pendulum at C' which would take it to K: now there are two equal forces acting on the pendulum—that of the blow which may be represented by $C'K$ and that of momentum, due to gravity, $C'b'$; both steadily decrease to zero; their resultant

swing to D, then
s. Were the blow
ing from b' toward a',
come $C'a'$, which with

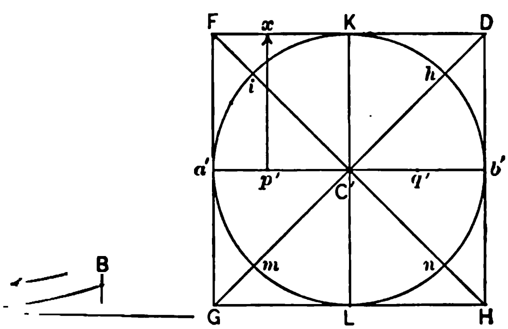


FIG. 47.

as before $C'K$, give a resultant $C'F$, and the swing between F and H.

been given at b', we would have the two ed by $b'D$ and $b'C'$—the former, the effect of ily waning; the latter, due to gravity, as stead- and hence their resultant a constant, that is, circle, and this circle, $b'hK$—etc., the pendulum And if the blow were given at a', nothing would except that the circle would be traced in the tion.

ose a blow were given, neither at the ends nor of the arc AB, Fig. 46, but at any other point, pendulum had attained only a *part* of its full then two *un*equal forces would begin their in- ner and continue unequal throughout, vary-

ing oppositely by the same amount; either, alone, would cause a straight line of different length to be traced, but both combined find their resultant in an ellipse, of which the lines are the axes.

Were the blow given at q', when the pendulum is moving from b' toward C', the direction of the axes would be changed.

In all the preceding cases, the pendulum being supposed to start from a', where gravity begins to act, *the successive points of application of the blow were but so many differences in phase* between the two motions caused by the two forces—the blow and gravity; and according to this difference in phase it is seen that straight lines, circles, and ellipses have been variously traced as the resultant path.

The movement of a pendulum under the influence of gravity and a physical impulse—a blow, is a tangible and visible means of illustrating the combination of two forces acting at right angles to each other; but beyond the few cases in which these forces bear a simple ratio to each other—as of equality, or as unity to any multiple of it—this method is not practicable: there is, however, a beautiful method that is capable of indefinite extension and variety of application, which will now be described.

36. Lissajous' tuning-forks in vibration.—In Fig. 48, F represents a tuning-fork armed with a pointed wire at one prong, and P a pane of smoked glass: when the fork is set

FIG. 48.

in vibration by a tap and held over the glass, as at B, the wire describes a straight line ss; but if at the same time the fork

...on in the direction of the arrow, the ...as curve *mn*—a visible tracing of the ... that are heard as a musical note; it is ...hose crests and troughs are at first high ...friction wears out the energy of the fork, ...s so, until, at length, the prong stops in a ...nd strikes the ear.

...tion can be made visible in another way. ... *T* are two tuning-forks, each having a little

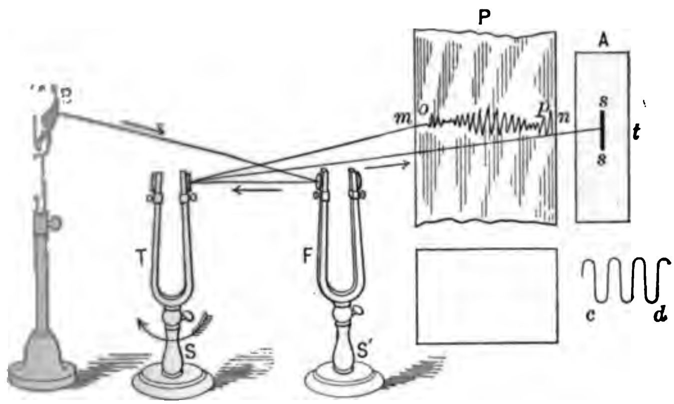


FIG. 49.

attached to one prong and a counterpoise to the other ... the forks being quiet, a ray of light comes from the ... passes through the lens *B*, strikes the mirror on *F*, ...ted to that of *T*, and thence to the screen *A*, where it ...s as a bright spot *t*. Now draw a violin-bow across the *F*, it will vibrate, and the ray striking its mirror, will ... up and down; it will be reflected by the mirror on *T*, ... is at rest, on to the screen *A*, as a vertical line *ss*; re- ... the fork *T* slowly, as shown by the arrow, and the ...ed light will be drawn out into the wave *cd*. Its ...nce is evanescent, however; the impression of light ... about $^1/_{10}$ of a second, and the wave appears and fades ...s rate.

Let the forks now be arranged as in Fig. 50, that is, T so as to vibrate in a vertical plane, and T' in a horizontal one: either, alone, set in vibration, would trace a line of light parallel to its plane of vibration, and hence these lines would be at right angles to each other. But set both forks vibrating, and, as in the case of the pendulum, the form of the resultant luminous curve will depend on the difference of

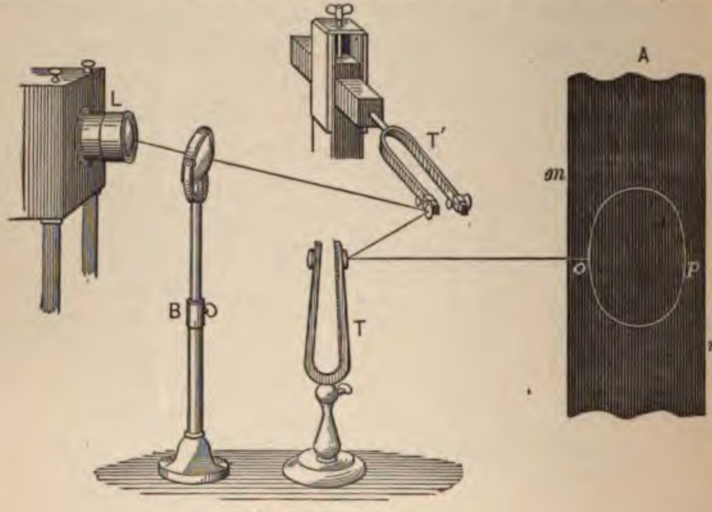


FIG. 50.

phase of the two forks and the ratio of their vibrations; the former—the phase—corresponds to the part of the pendulum's path where the blow was dealt, and the latter—the ratio of the vibrations of the two forks—corresponds to the relative strength of the blow and gravity. The two forks in the figure happen to have the same tone, and the second struck into the motion of the first when the latter was at the limit of its swing—at a stop, in fact, for an instant, and about to turn back. This case is therefore analogous to the one where the blow equal to the force of gravity was given the pendulum at the extremity b' of its arc, the resultant was a circle there, and so it is here. The phase there was the same

as the phase here—the forces there equal and at right angles to each other, as are the vibrations here—and the result is hence identical—a circle.

If the difference of phase be suitably varied we obtain straight lines, circles, and ellipses as shown in Fig. 51, top row.

It is evident that tuning-forks can be procured of every desired tone, and hence that any requisite ratio of vibrations of one fork to the other can be combined as in Fig. 50; the relative forces at right angles to each other (using the analogy of the pendulum) may thus be varied at pleasure, and this variety may be extended by continual change of phase in each ratio, so that the combinations become endless.

Some examples of resultant curves are shown in Fig. 51: the left-hand vertical row exhibits the curves for different ratios of vibration, as 1 to 1; 1 to 2; 1 to 3; 2 to 3; etc., both forks beginning together or without difference of phase: the horizontal row of each set shows how the primary curve varies when different phases are introduced.

37. Contrast of compass deviations with curves produced by two tuning-forks vibrating at right angles to each other.—The combination of separate curves is the converse of the procedure in Part Fifth of this Treatise: there, the resultant curve is given, to be resolved into components; these arise from the individual action of various magnetic bodies on the compass, and the intensity of this action may bear (for one body to another) any ratio, just as has been seen may exist for a series of tuning-forks; and it will be found that phase also has its analogue in the magnetic case, for different magnetic bodies begin their action at various points of the compass courses.

38. Coincidence and opposition of phase.—Recurring to Fig. 49, it is seen that both forks are placed so as to vibrate in the same plane: Suppose them tuned to perfect unison; then if both begin vibrating at the same instant in

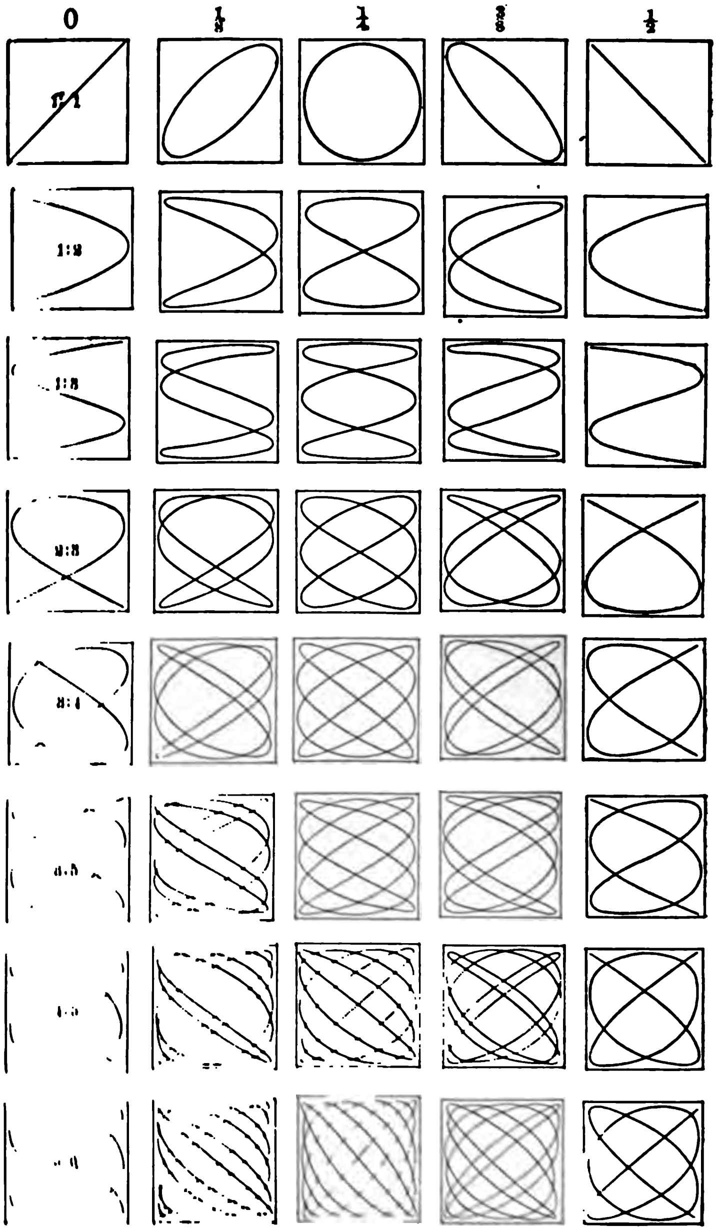


FIG. 51.

the same direction, or have identical phase, the vertical line of light described by *F* will be elongated by *T*, and the note that strikes the ear will be louder: but if the impulse of one fork forward be met by that of the other backward, then the line of light will be dimmed and the sound hushed. In the first case, or coincidence of phase, every particle of air and ether between the two forks that was set in motion by one fork, had this motion increased by the other fork; in the second case, or opposition of phase, the particles of air and ether were simultaneously urged in opposite directions by equal impulses, hence no motion, and consequently, neither sound nor light.

Now bring the forks to rest, and destroy their unison by placing a weight on the prong of one of them. Again set them in vibration *together*—their coincidence of phase will speedily be broken—the vibrations of one fork will alternately gain and slacken upon the other with recurrences of coincidence between: these are the "beats" of music—where the sound is reinforced, and the light, too, for upon looking at the curve on the screen *P*, it will be seen to be drawn out in long loops simultaneously with the beats reaching the ear, while the subsidence of sound corresponds to the contractions of the luminous curve. (See Fig. 52.)

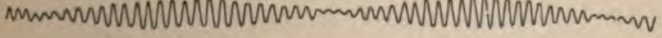


FIG. 52.

Thus by alternations of sound and silence coincidently with light and darkness, it is proved that there is interference of waves at the same instant in the same place in two distinct media—air, and some other, called ether: the air we know exists—is the ether less a reality?

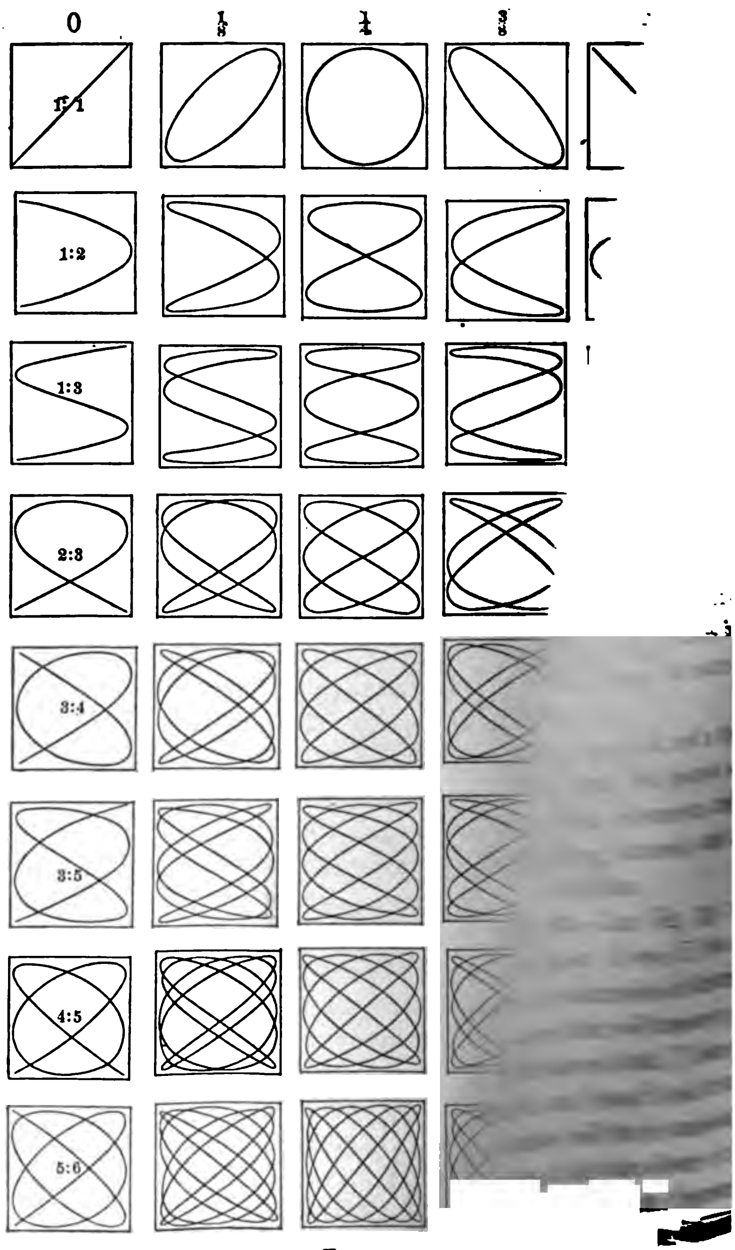


FIG. 51.

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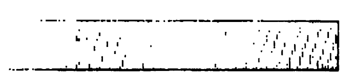


ɪɢ. 54.

·· one way nor the other, but re-
:ı in Fig. 54, by the uniform spac-
each approach of *T* toward *F* was a

step of interference—partial interference, growing more and more, until *T* reached the point *hg*, when it was complete interference, or opposition, producing silence.

And at every half wave-length, or any odd number of half wave-lengths of *T* from *F*, there will be similar opposition and silence.

41. Interference in waves of water.—Let two large stones be dropped into the water of a placid lake a few yards apart: they will give rise to two series of undulations that expand into widening circles. The distance of the centers of disturbance from each other may be supposed an exact number of wave-lengths of the kind caused by the stones, both the wave-length and the amplitude being considered the same for both series. This condition is shown in Fig. 55,

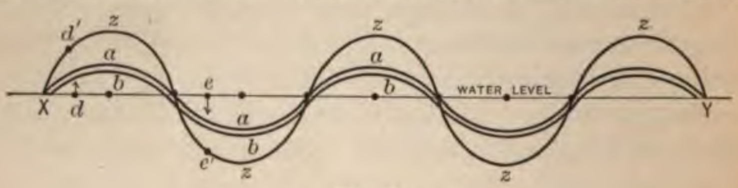


FIG. 55.

where the line *aaa* represents one series of waves and the line *bbb* the other: when they meet, as at *x*, the crests will coincide, and so will the troughs, and every drop of water thus subject to the double impulse upward, as at *d*, will be raised to *d'*; or to the double impulse downward, as at *e*, will be depressed to *e'*; and thus the resulting wave from coincidence of ridge and furrow throughout, will be *zzz*—higher elevations and deeper depressions than those of either series.

Now, let the distance apart of the centers of disturbance be shortened by one-eighth of a wave-length, as *xx*, Fig. 56: this difference of phase separates the two series of waves, *aa* and *bb*, and the combined impulses on the successive drops will produce the resultant wave *zzz*. A shortening of the distance by one-quarter of a wave-length, Fig. 57, only separates the

primary waves more—slides the wave *bbb* bodily, as it were, from left to right, and also the resultant curve, with the action on the differently located drops as indicated by the little arrow-heads. If the distance be shortened by one-half of a wave-length, as *xx'*, Fig. 58, then a crest of the second

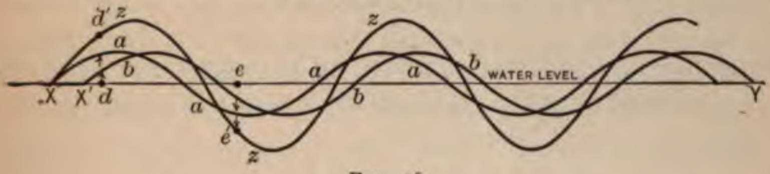


FIG. 56.

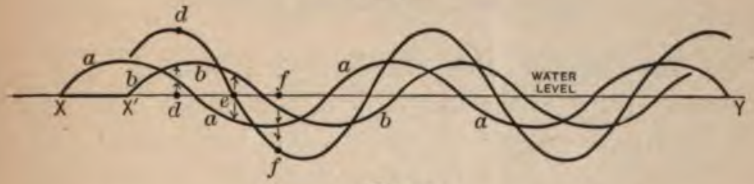


FIG. 57.

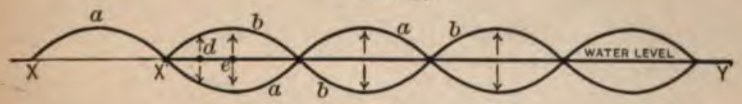


FIG. 58.

series of waves meets every drop on the level line at the same instant that a trough of the first series reaches it—there is equal and opposite contention, and this overlaps throughout, so that no drop moves from its state of rest.

Thus, in Fig. 56 there was interference of one-eighth wave-length; in Fig. 57, one-quarter; and as the difference of wave-length apart shortened, so the interference became greater, until finally, in Fig. 58, it is complete, or opposition, producing smoothness in the water, just as it did silence in the air. A further lessening of the distance apart, or, which is the same thing, increasing the interference beyond one-half wave-length, to five-eighths, three-quarters, seven-eighths, etc., would only reproduce in reverse order all the degrees of interference preceding that of the half-wave.

...APTER IV.

... OF WAVE-MOTION CHAR-
... RADIANT ENERGY.

... Interference of Waves.

... chapter.—It is to show that the ... phenomena with which ... that which gives rise to ... waves in the ether ... with the doubt of hy- ... of inference rather than

... directly—first by ... ground, and final ... except to those e...

... be shown ... heat, light, and ... the jung... the visible ... and impalpable

... might either ... completely destro... of sound ... both see and ... the medium—

water—was a material substance, apparent to both sight and touch; in the latter, the medium—air—was apparent to neither of these senses, but other proofs abound of its existence.

In both media, when complete interference occurred, with silence in air and smoothness in water, if one of the sources of disturbance were removed, there would immediately recur sound in the air and waves in the water: if the original dual source of disturbance were restored, it would also restore quiet to the air and water, and these alternations of condition might be repeated at pleasure.

If now, where neither air nor water exists, nor any other medium whose reality can be absolutely established, we find this phenomenon of interference in full growth and form, it is fair to infer that waves are there to produce it; FOR INTERFERENCE IS A PECULIARITY OF WAVE-MOTION. But waves of what? Surely, not of utter vacuity! Hence the ether.

43. Sound waves.—The alternation of silence with sound, as waves of air interfere or not, is so important as typical of interference in general that it will be illustrated by another method. Fig. 59 represents a speaking-tube

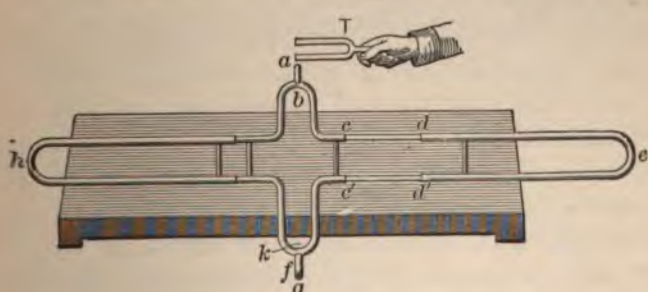


FIG. 59.

with openings at *a* and *g*, and two branches *bh* and *de*, the latter capable of sliding in and out, to vary the distance the waves of air will have to travel in it. When both

branches are of equal length, and a tuning-fork in vibration is placed at *a*, its note will be heard at *g* in full volume; but if the branch *de* is drawn out so as to make a difference of *one-half* wave-length between it and *bh*, then the note will be smothered: the waves in the two branches completely interfere at their juncture *k*, and silence is the result. If the branch *de* is drawn out until the difference in length between it and *bh* is *one* wave-length, the note will again be heard; and thus at every difference of an odd number of half wave-lengths—silence, and at every even number of half wave-lengths—sound.

44. Light waves.—To be exact, the title of this article should be "Waves that produce Light," and similarly for the other articles on interference; but the heading used, is preferred for brevity.

Now, we enter the domain of radiant energy, and the phenomena to be described will take place as well in a room void of air as in one filled with it at the normal pressure.

In Fig. 60 let *x* and *y* represent two small round holes, one close above the other in the wall of a room, by which sunlight is admitted. Everything in this and Figs. 61 to 66 is greatly enlarged for clearness.

The holes are closed with red glass so that only red rays can enter; these spread out in two conical pencils of light, of which *cxc* and *cyc* are vertical sections, and they overlap throughout the space *cvc*.

FG is the edge of a screen upon which the pencils of light fall, and Fig. 61 presents a full-face view of this screen as it would appear from *z*: it is seen that horizontal bars of red and black (represented by light and heavy shading) alternate regularly with each other in the space covered by both pencils: that the red bands exist, is most natural, for only red rays enter the room, but that these become extinct in symmetrically black spaces is matter for explanation.

The line *zA* in Figs. 60 and 64 is perpendicular to the

lines xy and ce, and the point z is midway between x and y. Fig. 64 is merely a portion of Fig. 60, in which the halves of two red bands enclose a whole black one, as shown in Fig. 65. The point A being equally distant from x and y, the rays meeting there doubly illumine it; but the moment we proceed from A toward b, the distance Ay lengthens and Ax

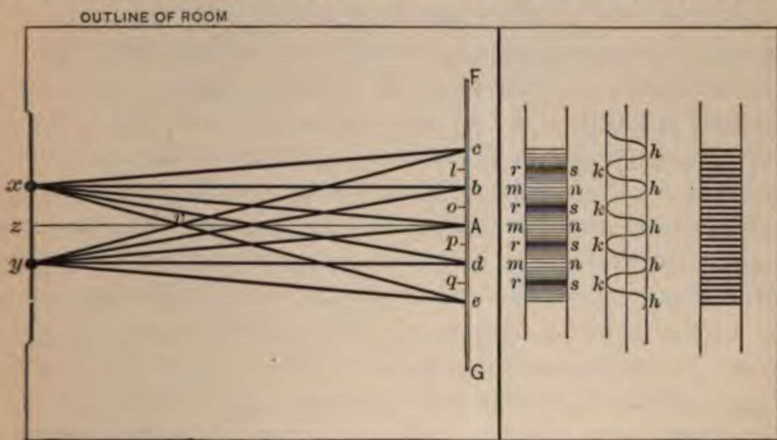


FIG. 60. FIG. 61. FIG. 62. FIG. 63

FIG 64. FIG. 65. FIG. 66.

shortens, with a corresponding fading of the red until it merges into an ashen hue that deepens and becomes black at o; this again shades off, blends into a reddish tint which brightens to full color at b. Now let us consider that the pencils of light entering the room are due to waves of a gaseous medium: at A two separate trains of these waves from x and y meet in the *same phase*, because the distance of A from their origin is the same; from A upward they get out of step at once—begin to interfere with each other—

because the distance each train of waves has to come, differs more and more from the other; hence the fading of the red and growing of the black; at *o* the difference in distance amounts to one-half a wave-length, therefore there is complete interference—extinction of all light; continuing toward *b*, the difference in path of the two trains of waves approaches more and more to one whole wave-length—the black lessens in tint, the red reappears and attains full brilliancy at *b*, where the difference in phase is an exact wave-length. And thus, upward and downward, at every point, *o*, *l*, *p*, *q*, where there is a difference of path of an *odd* number of *half* wave-lengths, there is darkness, and at every point, *b*, *c*, *d*, *e*, where this difference is an *even* number of *half* wave-lengths, there is light. Regarding the brightest points as summits, and the darkest ones as depths, and drawing a curve to represent the successive shading of one color into the other, we have a wavy outline, as in Fig. 62. If a piece of wood be placed over either hole, *x* or *y*, so as to prevent light entering it, all the alternations of red and black disappear, and one uniform tint—red—overspreads the screen from *c* to *e*, as shown in Fig. 63, by the equal spacing of the lines. Remove the wood, and the series of red and black bands return, and these conditions can be repeated at will: it is the analogue of the smooth water and silent air alternating with ridges and furrows in both media, according as one or two sources of disturbance were in operation. Thus wave-motion completely explains the dark bands, *and no other hypothesis will do it:* therefore light is due to wave-motion, and therefore also these waves must have a medium for their existence; for an *absolute* vacuum is incapable of transmitting this motion.

If the holes *x* and *y* were covered with any other colored glass—orange, green, blue—there would still be black bands alternating with others of the color used, the only difference being in the width of the bands—it would be less and less as colors approaching the violet were employed.

45. **Chemical waves.**—With only violet rays entering, let the screen be replaced by a plate coated with chloride of silver, and it will be found that the bands are photographed upon it—the chemical waves entering with the violet light interfere, just as the luminous waves do, and leave their impress where free to act, as well as fail of effect by reason of complete interference.

46. **Heat waves.**—Referring again to Fig. 60, remove the colored shades from the holes *x* and *y*, and place inside them a thin rectangular glass trough, so as to cover them; fill the trough with bisulphide of carbon, and all the radiations from the sun will enter the room, unobstructed by either the trough or its transparent contents: but drop into the liquid a few crystals of iodine, and at once all the luminous beam disappears—cut out, as if by a sharp instrument; the thermal rays remain, however, unimpaired, and in waves of radiant heat stream into the room in cones that overlap and fall upon the screen in bands of alternate cold and warmth.

These interference bands, however, cannot be seen, but their existence has been proved by observations with a very delicate thermometer or bolometer in every part of the space covered by the thermal radiations.

When the mingled waves of white light interfere side by side, as they do in the thin but varying walls of a soap-bubble, we merely have at one view in that evanescent film what is obtained singly by using different colored glasses to vary the hue of the rays entering the room.

Thus it has been shown that *interference* of water waves produces smoothness; of air waves, silence; of luminous beams, darkness; of thermal radiations, coldness; and of actinic rays, inaction; and so the nature of heat, light, and chemism is, by analogy, inferred from their behavior—that they are the result of *waves* in some medium.

47. **Electromagnetic waves.**—Later, evidence will be adduced tending to establish the fact that an electromagnetic

movement, produced artificially, is but an elongated light wave—that if it could be shortened to molecular size and produced with sufficient rapidity, it would affect the eye as light, and hence that both these phenomena are motions of the same medium.

The name "electromagnetic" implies a compound nature for the wave, and it is so in fact.

Whenever an electric stress in the ether is changing, there surrounds it another movement—a rotary motion of the ether: the electric current is but a mere filament of changing stress encased by circles of magnetic rotation. How such a dual motion can exist, may be inferred from a violent agitation of the air that is of frequent occurrence: consider the cyclone—it is a whirling body of air that reaches from the Earth upward; it does not attain full height at once, but first the air in one stratum begins revolving, then in another, then in still more in quick succession, until it develops into a towering column of spiral whirls swaying through space along a well-determined track, and expanding more and more as it progresses. Now the growth of this column from disc to disc may symbolize the propagation of electric stress that constitutes a current—a series of tense and lax conditions of the ether succeeding each other along a wire; the enlargement of the column as it advances on its path, like ripples from a center, may typify the spread of induction outward from the wire; and the rotary motion may represent the magnetic whirl—only, with this difference: that while the particles of air are driving bodily round the storm's center in spiral curves, the atoms of ether must be considered as so many beads strung along a common axis parallel to the wire, and all spinning round this axis. The wire would then be the visible core of a bundle of imaginary threads all parallel to it, each filled with atoms, and all on the same thread rotating upon it as an axis.

As the current increases, more threads arise out of the

quiescent ether—the string becomes a rope, the rope a cable, and the induction expands.

As the current weakens, the outer threads collapse and with them the magnetic field disappears. But all this is merely to afford a mental picture of what an electromagnetic wave may be, not actually is.

The conception may be illustrated by Fig. 67: in (1) is represented the flow of an electric current with beads of

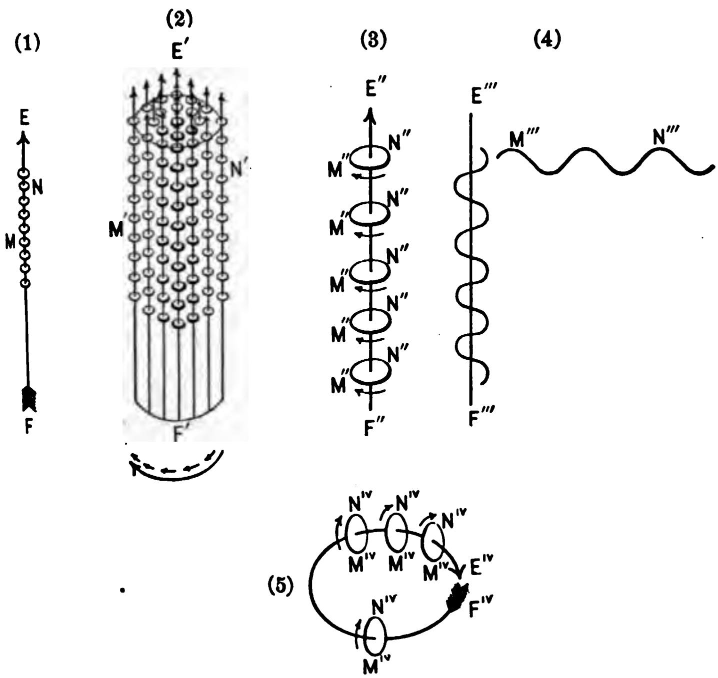


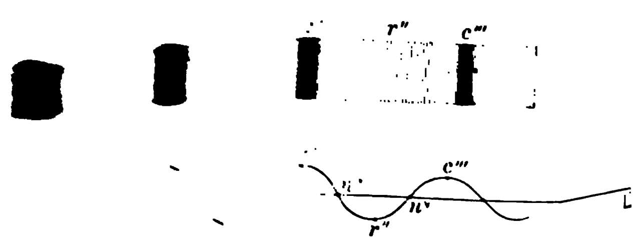
FIG. 67.

ether strung along it—all whirling; in (2) the current has grown in intensity, and parallel to it have arisen a number of imaginary axes each with its whirling particles—the magnetic field; the exterior boundary of this has the semblance of a continuous flow, as shown at F'. In (3) we have an exag-

stress passes from point to the successive discs of the two motions proceed every two sections of if we call one a crest them along their course by wavy line, since stress the other; this is the concurrently with this field at right angles; this is in (4); and both together

bent into a closed circuit. (5), whose importance will

have been ascertained of the area covered by it: arities of electromagnetic same way—exploring the instruments. The the electromagnetic wave process of doing this will of investigating it.



whose prongs are from them emanate of the air; represent

the density of the one by ordinates above a horizontal line LL' and the tenuity of the other by ordinates below this line, and draw a curve through the ends of both sets of ordinates; we thus have the figured wave beneath the pictured condition of the air. This agitation fades into stillness at a short distance from the fork.

Now suppose a wall, W, Fig. 69, to rise at n: the ad-

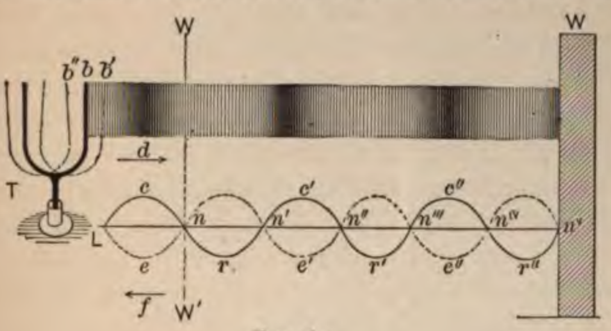


Fig. 69.

vancing particles of air will be reflected at n and turned back as represented by the dotted line e; the prong b was swinging to the right and reached its limit b' at the same instant that the air-compression denoted by C reached the wall; then the reflection of the air coincided in direction with the return swing of the prong to b''.

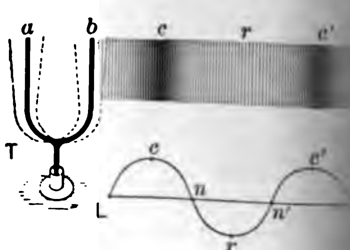
The figured part $Lcnc$ is the half of a *standing* wave—the direct sound and its echo; and the distance between the fork and the wall W erected at n'' represents six such halves, or three whole waves. Successive regular vibrations of the prong send out waves which are as regularly reflected at the wall and thus the motion of the prong right and left coincides with the motion of the air direct and reflected, and there is increased sound at the loops and almost silence at the nodes.

If we knew nothing of the condition of the air between the fork and the wall, and were to start at the latter with another tuning-fork, the twin of T, in vibration, as we ap-

gerated view of (1): as the ele[illegible]avelling fork would to point of the medium, it gives [illegible]; and we shall see rotation called magnetic, and t[illegible] our electromagnetic onward—yoked together. Be[illegible] both to discover the stress there must be a lax co[illegible] its loops and nodes and the other a trough, and ju[illegible]ectric tuning-fork like a curve, it will come out the [illegible] and laxity pass gradually o[illegible] direct and a reflected electric undulation, $E'''F'''$ i[illegible] remains motionless; must arise a variability in t[illegible] of water: these *nodes* the magnetic undulation M''' [illegible]—stationary waves, as form the electromagnetic wa[illegible]utward-bound undula-

If the conduit $E''F''$ of (3) [illegible] which had been turned it would make a vortex ring, [illegible] Nodes are therefore spots be seen later in this work. [illegible] all other points is fully

The characteristics of th[illegible] vibrate the tympanum of by observations at various p[illegible] eye, according to the and both the existence and [illegible] waves have been determined [illegible]ectric tension—of a power region of their influence w[illegible]re to become manifest: cyclone we find ready-made [illegible]ctromagnetic condition is we must make to order: a[illegible] power is neutralized. Suppose now be described as well as [illegible] to be electrified by waves [illegible] outward to the walls and [illegible]rigin—a succession of stationary [illegible] be true, sparks can be obtained [illegible]ertain points, and at others [illegible] contour of the wave, their [illegible] and node follow each other [illegible] positive that the hypothesis [illegible] verifying this will now be



In Fig. 68 let T be [illegible] vibration between the d[illegible] two bodies is one of the series of compressions an[illegible]: a delicate touch given

iodically to a pendulum will eventually set it swinging :r quite an arc; so the impulses communicated to the air a vibrating tuning-fork, will, if they fall upon a similar k at a little distance, cause it to hum a note in unison with own; and so, too, the sound of a violin will draw from a e of an open piano a responsive tone.

Now a charged Leyden jar, Fig. 70, of given size and

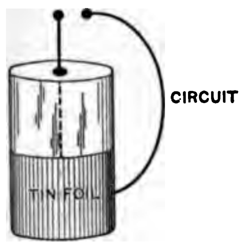


FIG. 70.

inite circuit will relieve itself of strain in a series of surg- s or oscillations of certain frequency; and by changing capacity of the jar, or the length or nature of the circuit, period or frequency may be varied just as the notes of ing-forks change with their size. Thus it is possible to ke one Leyden jar synchronize its discharge with another; which is the object sought, the discharge of one jar may, he wave hypothesis be correct, send out into space a suc- sion of electromagnetic waves, which, in their impact upon imilar jar at some distance, will charge this one until it erflows in a series of surgings. It is the parallel of one ing-fork projecting waves of air upon another. The rk of discharge of the second jar is the response to the rk of the first, just as the tone of the piano is to the note the violin. This is the principle of the experiment to be cribed, though the means of its execution is different.

Let *A* and *B*, Fig. 71, represent two plates of zinc with ck copper rods, *r r*, attached to them, having bright brass obs, *p* and *q*, at their ends. A small air-gap intervenes be-

tween the knobs. It is evident that this arrangement is essentially that of a Leyden jar, for the plates may represent the inner and outer coatings of the jar; and the rods with their knobs, the circuit whereby discharge will be effected when the tension is sufficient to cause a spark to leap across the air-gap. *R* is a thick copper ring of which a small section is cut away, and the ends fitted with knobs: its self-induction, capacity, and resistance are such that the rate of oscillation

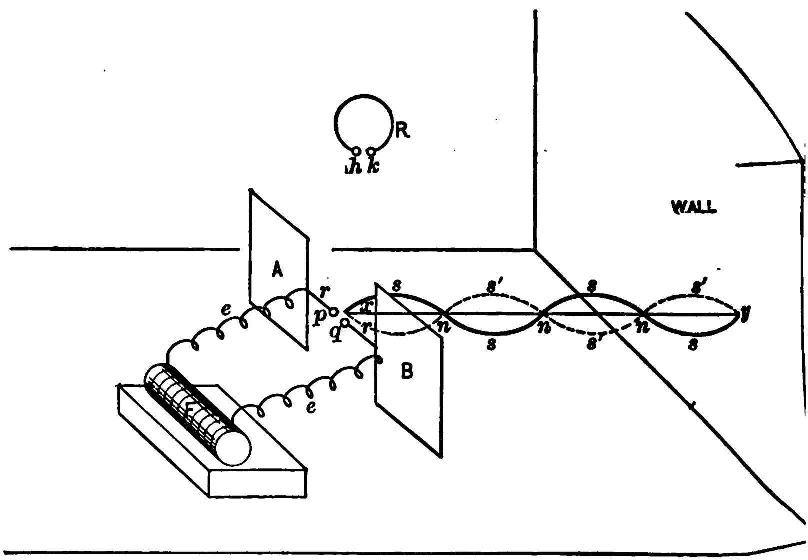


FIG. 71.

of an electric charge in it between the knobs *h* and *k* is the same as in the system of plates and rods between *p* and *q*: that is, these two bodies are electrically attuned one to the other: if they were strings of two instruments, as of a harp and a guitar, and in a similar way musically attuned, to thrum one would excite a sympathetic note in the other: *R*, then corresponds to the second jar. *F* is an induction-coil with its connecting wires, *e e*, to charge the plates. When this is done to overflowing, a spark will span the gap *pq*, and an electric

wave will surge across, say from *A* to *B*, emptying the former and surcharging the latter, so that a reverse rush takes place from *B* to *A*, and thus back and forth in quick succession for a few times with rapidly diminishing volume until equilibrium is restored. It is the analogue of a compressed spiral wire suddenly released—it will spring up and down a few times ere coming to rest. This flux and reflux excite ripples in the ether, which travel out in widening circles at right angles to the line of oscillation. Suppose these ripples to be propagated so as to form stationary electromagnetic waves as pictured in Figs. 71 and 72—one series suffering reflexion at

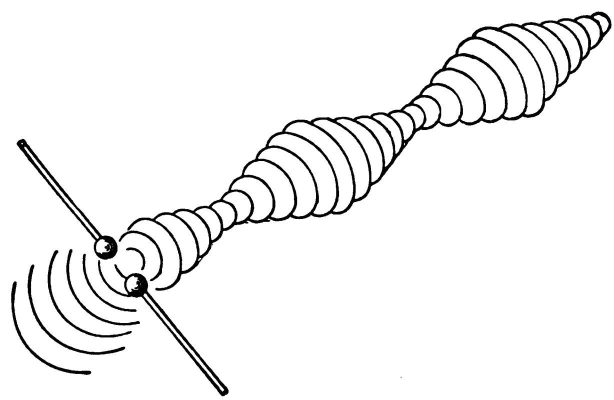


FIG. 72.

the sheet-iron wall *W*, and upon their return interfering with another series outward bound. If the space between the plates and the wall is in this condition, then by carrying the ring *R* along the line *xy*, it will have a current induced in it by the wave wherever active, and a spark will pass between *h* and *k*, but none where the wave is inoperative.

It may be inferred from what has been stated, that the discovery of the electromagnetic waves was the result of a fortunate hypothesis or haphazard experiment: not so. The induction-coil, the vibrator, the Leyden jar are all periodic in their action, and hence the field arising out of such action

may be analytically expressed by an equation which is essentially Fourier's series.

Prof. Hertz of Germany solved the equation and then proceeded to verify the results by experiment; and it is his experiments that will be used (not exactly as he made them, but in essence), to illustrate how the features of wave-motion —interference, polarization, refraction, etc.—run through electromagnetic phenomena in space, and hence indicate that these, too, are characterized by wave-motion.

In Fig. 71 the line xy is a perpendicular to the wall from a point midway between the knobs: beginning at y with the ring R held so that its plane is in the vertical plane through xy and the air-gap hk turned successively into different positions, no spark passes in this air-gap even while that at pq is brilliant with them, *until* the ring is moved from contact with the wall; then they begin—increase in size and brightness—fade and grow less—cease, and thus waxing and waning at regular intervals, disclose the powerful electromagnetic waves pervading space otherwise dark and quiet.

Here, then, are two features of wave-motion established: *interference* at the nodes n, and *reflection* at the wall.

The wall has a sheet-zinc facing, which reflects electromagnetic waves for the same reason that a mirror reflects light-waves, or a board-fence, sound-waves: but remove the zinc, and through the remaining brick, stone, or wood, though many feet thick, the wave will pass and produce a spark in R.

The existence of *standing* electromagnetic waves in space has been proven; the case is analogous to that of sound illustrated in Fig. 69: it now remains to show their existence in the case similar to that of sound illustrated in Fig. 68, where waves are not produced by interference.

In Fig. 73 let AB represent two plates with a system of rods and knobs, and F a small induction-coil to charge them; C and D are two similar plates from which long wires ww'

extend. Start the coil into action; it will charge *A* and *B*, and these will induce the electric condition in *C* and *D*, from which a current will result in the wire: now walk along the

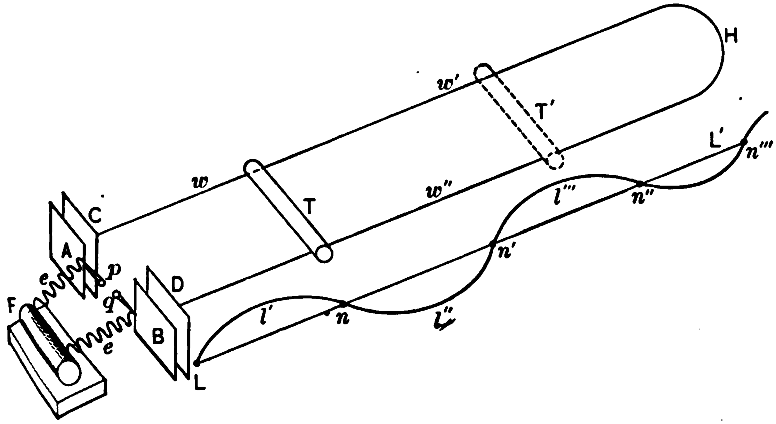


FIG. 73.

wire with the ear close to it but not touching it and a cracking sound will be heard; it grows louder, then drops—again louder, and again drops; we have *heard* an electromagnetic wave on the wire.

It can also be *seen;* for, place a vacuum tube *T* across the two wires and move it slowly along—it will alternately light up and darken as we proceed from *D* to *H*, and thus we have evidence of light as well as sound that the electromagnetic condition figured in the curve $l'l''l'''$ exists.

Section Two: Reflexion of Waves.

48. In the last article, *Reflection* was incidentally shown to be a feature of electromagnetic waves; it will also appear as a secondary event in the next article; but in the present one it is made a matter for illustration.

Reflection is such a familiar occurrence, that it seems superfluous to define it; still, to be explicit, this will be done.

If a particle of matter approach a plane perpendicularly, as in the direction *CO* toward *AB*, Fig. 74, it will rebound, if elastic, along the path it came; but if it meet the plane at *any* angle, as in Fig. 75, it will be reflected at the *same* angle

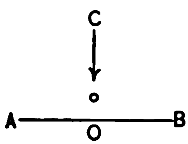


FIG. 74.

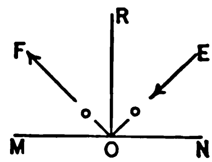


FIG. 75.

on the other side of the perpendicular to the plane at the point of impact; that is, if it arrive by the line *EO*, it will depart by *OF*, or the angle of incidence *EOR* is equal to the angle of reflection *ROF*.

We have instances of reflection in the billiard-ball glancing from the side of the table; in the waves of the sea recoiling from the breakwater; in the echo of sound from the cliff; the flashing of light by a mirror; and the turning aside of heat radiation from an open grate by a screen.

To show, in particular, that electromagnetic waves are reflected just like material particles, or like waves of air or water, consider Fig. 76: *A* and *B* are two parabolic mirrors placed side by side with their focal *lines* *F* and *F'* vertical (the peculiar property of this kind of mirror will be explained in the next article); *ss* is a screen faced with sheet zinc and the inside of both mirrors is covered with the same material; *PP'* is a perpendicular from the middle point between the focal lines to the screen, and the mirrors are turned so that the lines *mP* and *nP* from their focal lines will make equal angles with *PP'*; *V* is a vibrator consisting of two short thick brass cylinders with knobs at the ends nearest each other, the knobs being separated by a little air-space; *WW* are wires connecting the induction-coil *C* with the vibrator; *R* is a metal ring with a small section cut away and the ends

fitted with knobs; its size is such as to make it electrically attuned to one of the wave-periods that the vibrator *V* is capable of sending forth.

When the induction-coil is set in action, it charges the vibrator—in principle a Leyden jar—whence electric oscillations pass to and fro between the knobs, following a spark.

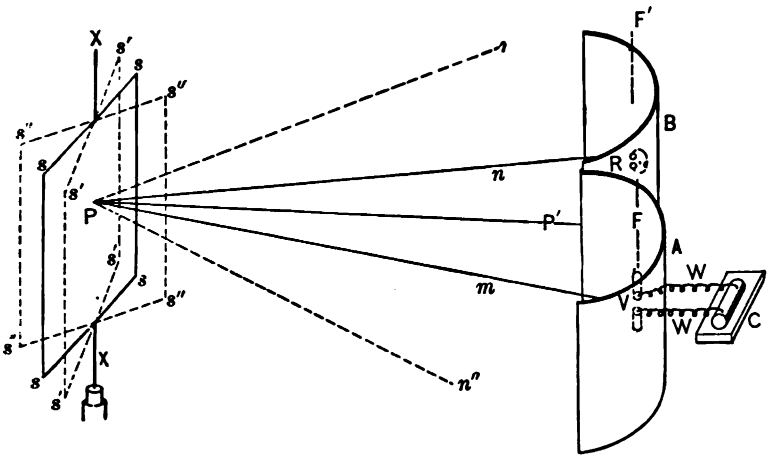


FIG. 76.

These oscillations create waves in the surrounding ether, which are collected by the mirror *A* and thrust in parallel rays upon the screen; this *reflects* them into the mirror *B* where they are concentrated upon the resonator *R* and a series of responsive sparks between its knobs is the result. But if the screen be turned into any other position than perpendicular to *PP'*, as, for instance, *s's'* or *s''s''*, the reflected rays will take the directions *Pn'* and *Pn''*, and no longer produce sparks in *R*, even while the vibrator is brilliant with them.

The *reflcction* is therefore as direct and concentrated as would be that of material particles.

If a particle of matter approach ...
as in the direction CO toward AB, ... aves to a Focus.
if elastic, along the path it came; ...
any angle, as in Fig. 75, it will be ... by the revolution of
... A', Fig. 77, represent
... F' the focus of each.

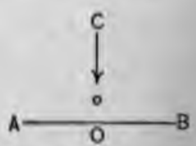
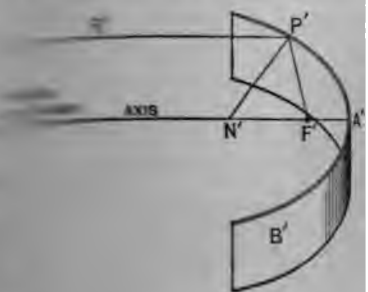


FIG. 74.



on the other side of the perp...
point of impact; that is, if ...
depart by OF, or the angle of ...
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We have instances of refl...
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To show, in particular ... or ether, arising at F and
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water, consider Fig. 76; ... is now diffused and uni-
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the next article); xs is ... mirror, $P'A'B'$, be symmetri-
... of both mirrors ... the parallel fragments of the
... is a perpendicular ...
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... lines mP and nP ... at F; its ticking will be dis-
... with PP'; ... spot and remove the second
... brass cylinder ... an ear at F; but with the
... the knobs be ... will return. For heat-waves:
... wires connecti... with boiling water at F and a deli-
... a metal ring ... will rise because of the

concentrated on it; if the second mirror be removed, the temperature falls—if restored, it rises again. For light-waves: place a small glow-lamp at F and a dazzling spot will appear at F', which gives place to a uniform light, if the second mirror be taken away, only to return when in place again. And thus, at pleasure, we can have at F', sound or silence, warmth or coolness, blinding brilliancy or grateful glow, according to the nature of the source of waves at F and whether the second mirror be in place or not.

To show that electromagnetic waves are similarly reflected and brought to a focus, a small change is made in the form of the mirror: as described, its focus is a point, but if a series of parabolas like PAB be laid one upon another in symmetrical pile, the several focal points thus superposed will form a focal *line*. The interior of the mirrors should be coated with tinfoil. Then inside them the apparatus of Fig. 76 is to be adjusted—the vibrator V in one, and the ring R in the other, and both so that their knobs shall lie in the focal lines of their respective mirrors. Now when a charge on V breaks across the air-gap as a spark, it will excite electromagnetic waves in the ether which will expand to the surface of the mirror PAB, there undergo reflection, proceed in parallel lines to the second mirror, and be reflected from its surface into converging lines; these, falling upon the ring R, will induce a current in it that will leap as a spark between its knobs. But if these knobs be moved out of the focal line, there is no responsive spark; nor will there be, if the second mirror be taken away—the force of the waves reflected from the first mirror is too diffuse to excite the necessary charge in the ring.

Section Four: Refraction of Waves.

50. Light waves.—Refraction is a feature of wave-motion that is found in electromagnetic phenomena as well as in Sound, Heat, and Light. Refraction of Sound will be brought in as an eye-witness, for the *air* and its *waves* we *know* exist; but the ether and its undulations are more of the nature of circumstantial evidence—worthy of credence in the highest degree, but still with a possible haze of doubt clinging to them.

Generally stated, refraction means a change in both the velocity and direction of a moving wave on entering one medium from another of different density, as from air to water: this is illustrated in the case of sound in art. 51; it may also be illustrated in the case of light by defining the *index of refraction*. Let *RIBG*, Fig. 78, be a shallow vessel

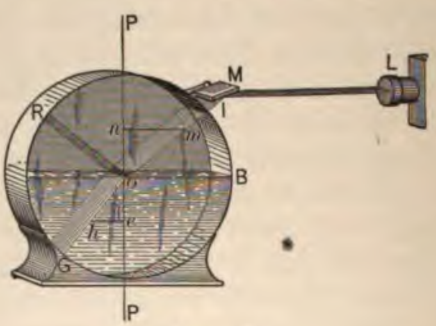


FIG. 78.

covered with glass; it is half filled with water slightly whitened by milk and the air above is smoky from a puff from a cigar; a beam of light from a lamp *L* is reflected by a plane mirror *M* in through a slit *I* in the rim. The direct beam *mo* is visible in the smoky air, and its bent, or refracted, continuation, *OG* is in the milky water. *PP* is perpendicular to the surface of the water, and *mn* and *he* are two perpendiculars to

PP from *any* points of the path of the beam. Divide the radius of the vessel *OB* into any number of equal parts, say 100, and measure *mn* and *he* by this arbitrary scale; divide the number representing the former by that denoting the latter, and the quotient is the Index of Refraction. It is constant for the same two media, but varies when these are changed. The line *mn* is the sine of the angle (of incidence) *mon*, and *he* is the sine of the angle (of refraction) *hoe*, so that the index of refraction is equal to the quotient of these sines.

It may be stated in passing that a similar law has been mathematically deduced for electromagnetic waves—only, that for these, the ratio is of the tangents instead of the sines of the angles. Thus the fact of electromagnetic refraction was analytically established prior to its experimental proof.

If a ray *R* of any single color—red, blue, yellow, etc.—meet a prism of glass, *ABC*, Fig. 79, at a *certain* angle, it will

FIG. 79.

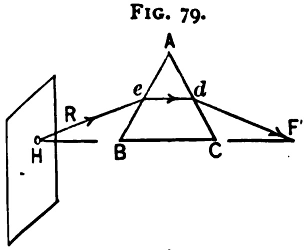
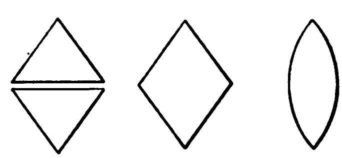


FIG. 81. FIG. 82. FIG. 83.



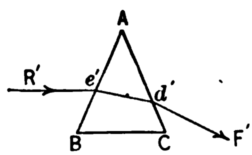


FIG. 80.

be bent parallel to the base as in *ed*, and emerge in the direction *dF* symmetrical with *Re*: if the ray be parallel to the base before entering, it will be bent toward it *in* the prism, and still more so on emergence as in Fig. 80. The transition from

Section Four: Refraction of Wave

50. Light waves.—Refraction is a featur tion that is found in electromagnetic phenome Sound, Heat, and Light. Refraction of S brought in as an eye-witness, for the *air* and *know* exist; but the ether and its undulations a nature of circumstantial evidence—worthy of c highest degree, but still with a possible haze of to them.

Generally stated, refraction means a char velocity and direction of a moving wave c medium from another of different density. water: this is illustrated in the case of sou may also be illustrated in the case of ligh *index of refraction.* Let *RIBG*, Fig. 78, b

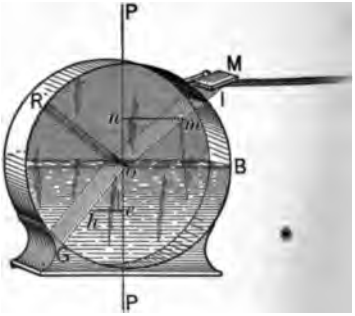


FIG. 78.

covered with glass; it is half filled ened by milk and the air above is cigar; a beam of light from a lam mirror *M* in through a slit *I* in the is visible in the smoky air, and i tinuation, *OG* is in the milky water. surface of the water, and *mn* and

of the wave-front; it strikes the lens at *o*, the middle is at once retarded in the denser medium while the ends travel on with their original velocity in air until they reach the points *m* and *n*; by this time the middle has reached *o'*, a less distance than *am* or *bn*, and so the wave presents the broken front *mo'n*; the ends immediately emerge into air and proceed as before while the middle is still retarded by the heavy carbonic acid gas until it reaches *o''*, when all parts of the wave go on in air, but in two columns *a'o''* and *b'o''*; these gradually converge to produce their full effect at the focus.

52. **Heat waves.**—The refraction of Heat has been effected by the apparatus shown in Fig. 86: a prism of rock

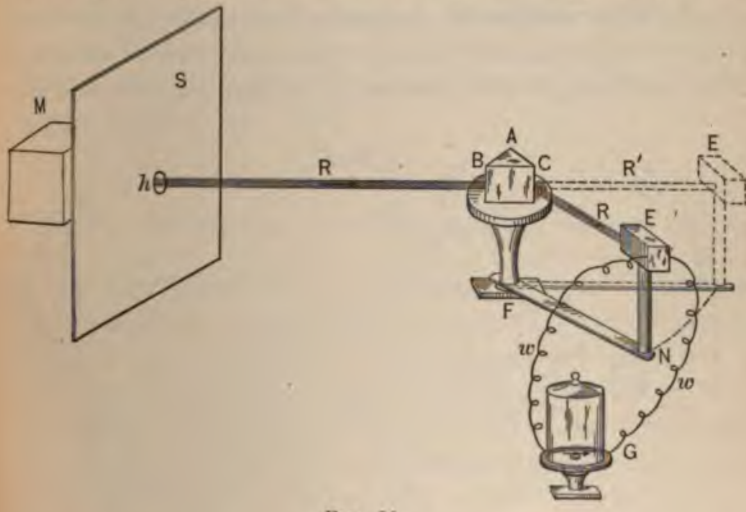


Fig. 86.

salt *ABC*, which allows heat to traverse it freely, is placed on a stand; *E* is a thermo-electric pile—a combination of bars of antimony and bismuth—from which wires lead to a galvanometer *G*; when heat-waves fall on the ends of the bars, which are alternately soldered together, they excite in them a current of electricity which is conveyed by the wires to the galvanometer and moves its needle. The bar *FN* is pivoted at

F, so that the pile *E* may be revolved into any position. *M* is a copper cube filled with boiling water and screened off to prevent heat reaching the pile except through the hole *h*.

Before placing the prism on the stand, and with the pile at *E'*, in the direct line from *h*, the rays of heat *RR'* fall upon it, and the needle swings in response to the consequent current: but with the prism placed on its stand, the needle instantly returns to zero, and before it moves again as indicative of heat falling on the pile, the latter must be revolved through a considerable angle—into the position *E*. Thus, as in the case of light, Fig. 80, the heat-waves are *bent* by the prism—refracted—into the line *RR*.

53. **Electromagnetic waves.**—The mode of procedure to show the refraction of electromagnetic waves is similar to that described in the preceding article. Fig. 87 will illustrate it—a reproduction in part of Fig. 77: *PAB* is a parabolic mirror, and *V* a vibrator and *R* a resonator similar to those shown in Fig. 76; *P'A'B'* and *P''A''B''* are two positions of the second mirror; both *V* and *R* are to be adjusted vertically in the focal lines of their respective mirrors; *XYZ* is a

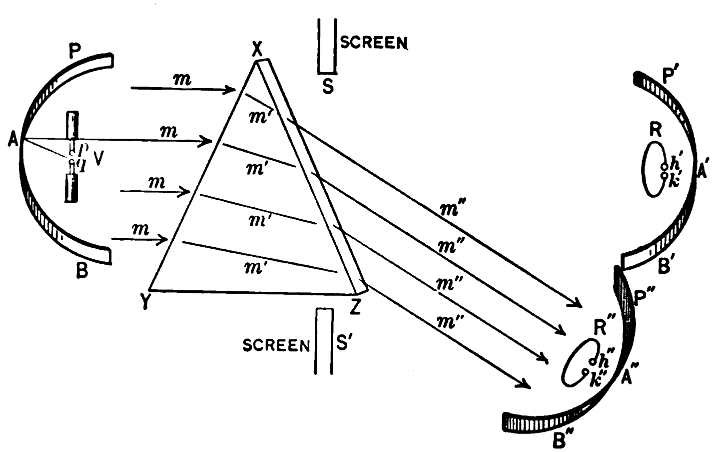


FIG. 87.

very large prism of pitch; S and S' are two *zinc* screens so placed as to intercept all waves other than those that have passed through the prism. When the prism is *not* interposed, a spark passing between the knobs p and q will excite a spark between the knobs h' and k' placed in the direct line from the first mirror; but when the prism is in place as shown, no spark will occur in the ring R, even while the vibrator is sparking, *until* the second mirror is moved many degrees out of the direct line, or into the position $P''A''B''$.

The index of refraction given by this experiment was 1.69, which nearly agrees with the index (1.5 to 1.6) found for pitch-like substances by optical experiments.

And thus refraction points to the kinship of heat, light, and electricity—that they are due to the undulations of some medium, since sound, which is due to waves of air, is refracted in precisely the same way.

Section Five: The Polarization of Waves.

54. **Light waves.**—So far, four phenomena have been used to illustrate wave-motion—interference, reflexion, convergence, and refraction. Interference was described for waves of water, air, and ether; and thus phenomena in the last medium, which is hypothetical, was connected through the invisible but none the less real air with similar occurrences in water, which is material enough to carry conviction to any mind. The tie being thus established for the existence and action of waves in various media, the gross water was dropped out of the illustrations of reflexion, convergence, and refraction; but the bond was further cemented by description of these phenomena in both air and ether: now, however, a step beyond must be made—an advance into regions wholly ideal, and a phenomenon described that is found only in the ether—Polarization. It is a characteristic alike of heat, light,

chemical, and electromagnetic waves; and as it has been pretty satisfactorily established in the foregoing pages that a medium must exist for these actions and that the mode of propagating their energy is by a wave, what follows is by way of confirming this view. Polarization, then, is only another link connecting electromagnetic waves with the other waves of the ether—the luminous, thermal, and actinic.

Just as a source of sound is a center of aërial disturbance, or a stone thrown into water gives rise to a series of expanding ripples, so a source of light creates commotion in the ether, which travels outward in straight lines, called rays.

The molecules of water do not advance with the wave, but rise and fall across a mean line drawn in the direction of the undulation; and this, too, is the motion of the particles of ether—across the progress of the ray—only, that whereas the drops of water move up and down alone, the ether particles move in every direction across a center, as diameters cross that of a circle; and it is the propagation of this kind of motion to the particles of ether lying in a straight line that constitutes the velocity of light. When the commotion reaches the eye it causes the sensation of light. The idea intended to be conveyed is illustrated in Fig. 88, where the arrow represents

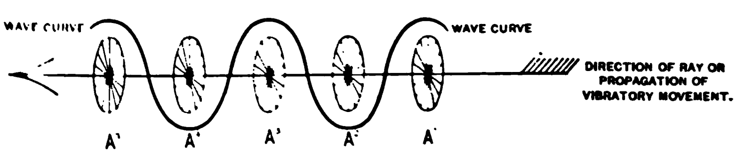


FIG. 88.

the direction of the ray, and the circles, successive stages of the oscillatory movement as it reaches the particles lying along it. Slide the circles along the arrow until they are in close proximity, and it will represent the continuous condition of the ether. Between any two particles in the *same* phase, as in A^1 and A^3, there will be particles in every inter-

mediate phase, as shown in Fig. 15, page 37: this indicates that the propagation of light is by the undulatory movement there delineated.

This matter of the oscillation of the ether particles will be further illustrated. Consider Fig. 89: *A* is a cluster of small

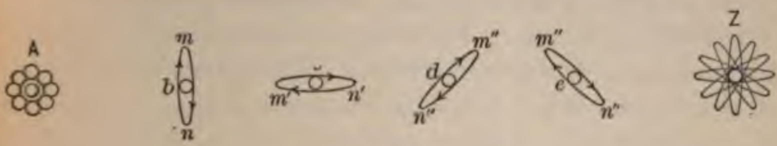


FIG. 89.

ivory pellets tied close down to a board with indiarubber threads; *b* is a single one of these pellets; pull it vertically to the elastic limit, *m*, of the thread and let it go; it will swing to *n*, and continue oscillating until friction both of the medium and of the parts of the thread exhausts the energy: similarly, *c*, *d*, and *e* are drawn horizontally and in inclined directions—they all may represent particles of ether swinging to and fro. Now unite a multitude of such particles, let each oscillate in a diameter of the same circle and we have *Z*—one of the stages, $A^1 A^2 A^3$, etc., of the ether along the ray in Fig. 88.

Material atoms in intense vibration are sources of light: let one such atom occupy the center of the cluster at *A*, Fig. 89, and the ivory pellets represent so many particles of ether surrounding it; the pellet is pulled out by the hand—the ether is pushed out by the vibratory change of form of the atom; the pellet swings back on account of the elastic force of the thread that ties it down, and the ether does the same because of its inherent elasticity. Violent expansion and contraction of the vibrating atom keeps up the commotion—drives the ether outward and permits it to close in again, and as each particle swings in a radius, all are thus oscillating in an infinity of radii from a center—a starry nucleus as represented at *Z* in Fig. 89.

As regards the constitution of the ether, I may quote the following opinion, which, however, was not expressed in connection with the illustrations here, which are solely the author's:

"I do not say that the medium [the ether] is thus made up of discrete particles, or that the different portions of it vibrate in this manner; but there is undoubtedly a directed quantity transverse to the direction in which the wave is travelling, the value of which at different points may be represented by the displacements of the particles." (Prof. Andrew Gray, F.R.S.)

In Fig. 90, a ray of light, *AO*, made up of starry elements

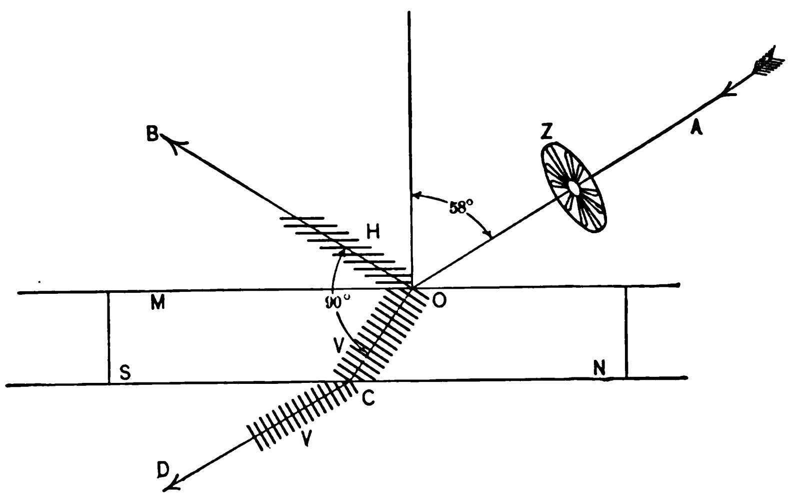


FIG. 90.

like *Z*, Fig. 89, approaches a slab of glass, *MN*, at a certain angle, 58°, called the polarizing angle: the ***horizontal*** oscillations of the several elements, such as *c*, Fig. 89, considered perpendicular to the plane of the paper in Fig. 90, or *hh'*, Fig. 91, striking the glass on their sides, as a flat stone glances along the water, are *reflected* like a series of bars, *H*, spaced along the direction *OB*, each parallel to the upper surface of

the glass; the vertical oscillations, on the contrary, such as *b*, Fig. 89, and *vv'*, Fig. 91, meeting the glass endwise, strike into it, as the stone would enter water if its edge met it; and they are *refracted* like a succession of bars, *V*, Fig. 90, along the line *OC* in a *plane* at right angles to the face of the glass.

The oscillations inclined at an angle, as *d* and *e*, Fig. 89, or *ee'*, Figs. 91 and 92, are each resolved into two components, one horizontal, as *st*, and the other vertical, as *se* + *te'*. Thus,

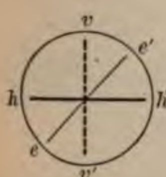


FIG. 91.

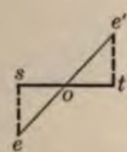


FIG. 92.


FIG. 93.


FIG. 94.

while the ray *AO*, Fig. 90, met the glass, oscillating in the directions of the spokes of a wheel, it ceased to do so after impact, but became restricted to two directions; what was *reflected*, was composed of oscillations only in a plane parallel to the face of the glass, as in Fig. 93, while that *refracted* had only oscillations in the plane perpendicular to that face, as in Fig. 94. This is polarization. It is a condition of light that may be produced by other means than reflection and refraction, and consists, as indicated, in reducing the ether oscillations from radial directions to parallelism.

The behavior of polarized light is illustrated by Figs. 95 to 98: in each, *a* and *b* are two plates of glass blackened on one side in order to have only a single reflecting surface; *a* is seen endwise in all and *b* is so in Figs. 95 and 97—that is, their reflecting surfaces are perpendicular to the plane of the paper; in Fig. 96, *b* is turned so as to present its front at an angle to the observer, and in Fig. 98, it is turned with its back in a similar way; the ray *P* is the natural sunlight as it enters through some aperture and strikes the plate *a* at the polariz-

ing angle; when reflected in R it has only oscillations parallel to the surface of a—their ends are seen in the ray. The vertical oscillations striking the glass edgewise are all broken up (compare in this connection Figs. 91 to 94, which will explain the process). In Figs. 95 and 97, the oscillations of R

FIG. 95.

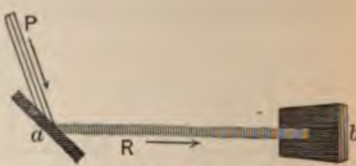


FIG. 96.

FIG. 97.

FIG. 98.

fall upon b on their sides and are *reflected* in E and F; but in Figs. 96 and 98 they encounter b endwise and are destroyed, hence no reflected ray.

Many substances are variously dense in different directions of their structure: ice, for instance, is more compact straight down into it, than along its surface, and wood is of closer texture with the grain than across it. Several crystals have the same characteristic, among them tourmaline and Iceland spar.

It has already been shown that a difference in density of two media produces refraction: the same is true of a difference of density in two directions of the same medium, so that a ray of light entering such a substance will be differently refracted—split into two parts that will traverse it, each in its own direction, with its own velocity. Tourmaline exists in several

varieties and colors; it is of uniform density in a certain direction called the axis of the crystal, and also at right angles to it, but of different degree from the other: a ray of light, therefore, entering the crystal, will suffer double refraction—be divided between two paths; but while that parallel to the axis is an open passage, the one across it is completely barred. The light emerges polarized—oscillating parallel to the axis of the crystal only. This is illustrated in Figs. 99 to 102: in 99, T

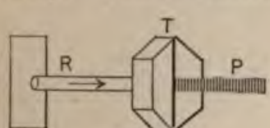


FIG. 99.

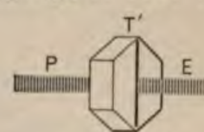


FIG. 100.

is the tourmaline with its axis in a vertical plane; R is a pencil of natural light, it emerges at P reduced to oscillations parallel to the axis only; in Fig. 100 a second plate of tourmaline, T', is placed with its axis parallel to the first, and through it the polarized ray P passes without hindrance, emerging at E, still polarized like P; in Fig. 101 T'' is another plate of tourmaline turned with its axis at right angles to that of T', and the polarized ray P is thereby completely stopped; in Fig.

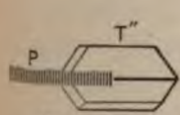


FIG. 101.

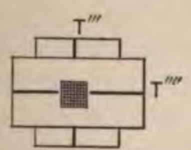


FIG. 102.

FIG. 103.

102 two plates of tourmaline, T''' and T'''' are crossed, thus quenching the brightest light—a black spot appearing where light should be. Tourmaline is most valuable for determining the condition of light; if plane polarized, the crystal gives free passage to the oscillations in one direction, but opposes them completely in another, just as a row of parallel bars would a card, Fig. 103.

Iceland spar is a transparent substance that also produces double refraction, but, unlike tourmaline, both rays emerge intact. Fig. 104 represents such a natural crystal: ***bdek*** is a

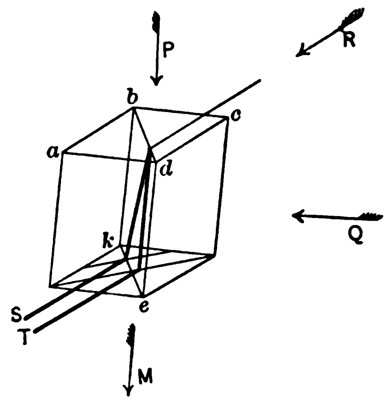


FIG. 104.

plane through its axis, and any ray, *P*, entering the crystal in or parallel to this plane, will emerge as at *M* undivided, as from a block of glass; but if the incident ray departs from parallelism with this plane, as at *R*, it will be split in its passage through the crystal, and emerge as two parts, *S* and *T*, the oscillations of which are at right angles to each other as illustrated in Figs. 93 and 94, and which may be verified by a plate of tourmaline, as in Fig. 103; and the greater the angle between the incident ray and the direction of the axis in Fig. 104, the more will the polarized rays *S* and *T* separate, until, when it is 90°, as at *Q*, the divergence is greatest. On further increase of the angle, the rays approach each other, and when it has become 180°, they are again together. If *P* be a vertical axial line of the crystal, and *R* a ray making *any* angle with it, then if this revolves in a cone around *P*, so will *S* and *T* describe cones about *M*, its prolongation.

Of Iceland spar an instrument is made—a Nicol prism—that will now be described, as it is used in experiments to

prove the polarization of heat. Fig. 105 represents a block of the spar: to make the Nicol, this is cut diagonally into two pieces from H to K', the two surfaces of the cut are smoothly polished, and again united by means of a cement, so that the crystal presents its original aspect: but the layer

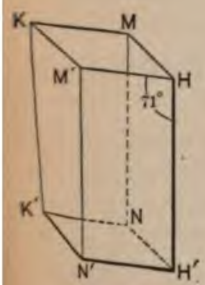


FIG. 105.

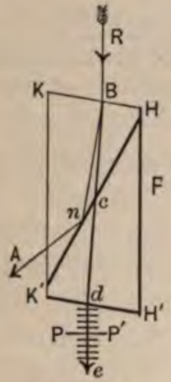


FIG. 106.

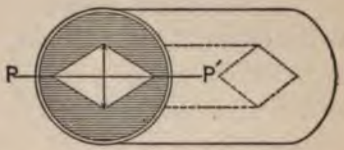


FIG. 107.

of cement which now lies in its interior has the property of deflecting one of the two refracted rays entirely out through the side of the prism, while the other is allowed to traverse its length. Fig. 106 shows a section of the block in Fig. 105, through the edges HH'—KK': HK' is the line of the cement. The ray R incident at B enters the prism, is split into the two polarized rays Bc and Bn: the latter suffers total reflection in nA, while the former continues on to d and emerges toward e with the oscillations polarized as represented parallel to the section HKH'. The prism is set in a case as shown in Fig. 107, the line PP' of the longer diagonal being the direction in which the oscillations take place. Two such instruments may be used jointly as polarizer and analyzer, for either will afford a polarized ray as illustrated in Fig. 106, and the other placed in the path of this ray will indicate the action of the first. If placed as at A and B, Fig. 108, with their longer diagonals parallel, a ray R entering the first, will give a polarized ray P,

which will pass freely through B and emerge at E, polarized as it was in P: but if B be gradually turned round a horizontal axis through its length, the ray E begins to fade, and becomes extinct when B has acquired the position C, its longer diagonal at right angles to that of A, or the Nicols are "crossed."

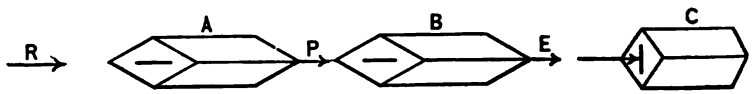


FIG. 108.

It is similar to the action of the tourmalines in Figs. 100, 101, and 102.

Polarization covers an extensive and intricate field of physical research, but only such part of it has been described as is necessary to point out the connection between heat, light, chemical action, electricity, and magnetism—that these are all manifestations resulting from waves in the ether. There is one phase, however—circular polarization—that will be briefly illustrated by a simile as its use comes in later. Imagine a wheel of many spokes turned slowly on its axle at the same time that it is rapidly pushed along this axle: if the spokes represent lines of oscillation of ether particles and the tire the limit of their excursion, then this tire will enclose a region of triple movement; an in-and-out motion—the oscillation of the particles, a rotary motion—the revolution of the wheel as a whole, and a translatory motion—its thrust along the axle, and all resulting in a kind of spiral wave—circular polarization. But this may have a visible representation in the case of a garden hose; if, while held in the hand, the nozzle be swung round in a circle, the issuing stream will no longer appear like a straight glass rod, but a spirally advancing wave.

In a former article, it was shown that an oscillating pendulum, which in reality swings in wave-motion, describes a straight line, a circle, or an ellipse, according to the point of

its path at which a blow was dealt it: so, too, waves of ether entering a plate of quartz are made to act upon each other in such manner that circular polarization is the result—the particular structure of this crystal is to the ether-waves what the blow was to the pendulum that produced rotary motion. The peculiar crystallization of tourmaline, on the other hand, produces right-line motion, or plane polarization; and there are other crystals that cause elliptical polarization.

55. **Actinic waves.**—Ether-waves that produce chemical effects have been plane polarized by tourmaline and the result shown on a plate coated with chloride of silver. Referring back to Figs. 99 to 102, if a sensitized plate be exposed to the vibrations *P* coming from the first crystal or to those at *E* emergent from the second, the action upon the chloride of silver will be rapid; but if the second crystal be turned as in Fig. 101 or both be crossed as in Fig. 102, and a new sensitized plate be exposed, no action whatever will take place, thus proving that the actinic rays entering the first crystal left it plane polarized. It is entirely analogous to the case of light.

56. **Heat waves.**—Ether-waves that produce heat have been polarized by an apparatus represented in Fig. 109: *L*

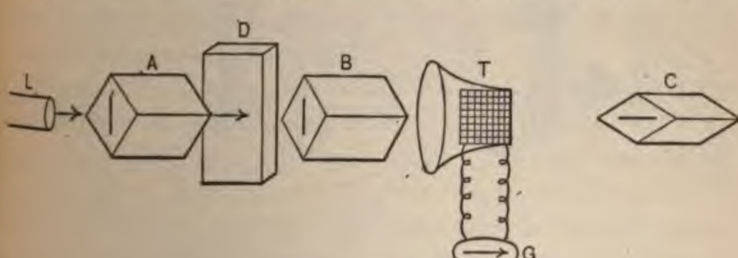


Fig. 109.

is an electric lamp; *A* and *B* two Nicol prisms with their axes vertical and parallel; *D* is a trough filled with bisulphide of carbon having some iodine dissolved in it—a solution that in-

tercepts the brightest light but allows obscure heat to pass freely; T is a thermopile and G a galvanometer. With the Nicols placed as shown at A and B and the galvanometer needle at zero, the cap covering the lens at L is removed, and immediately the needle jumps wildly around from the effect of the flood of rays emitted from the lamp—they pass through A, are there polarized, emerge as vertical oscillations only, are completely shorn of their luminosity by D, pass through B as obscure oscillations, fall upon T, and excite in it an electric current that moves the needle at G. But now turn B around a horizontal axis, as shown at C (but in the place B occupies), until the Nicols are "crossed" and at once the vertical oscillations are barred and the needle returns to zero. And so by alternate parallelism or crossing of the prisms, passage or obstruction is produced, as shown by the corresponding swing or return of the needle.

57. Electromagnetic waves.—The polarization of electromagnetic waves has been effected by a procedure similar to the foregoing, only that suitable electrical means were employed. These are represented in Fig. 110: A and B are two

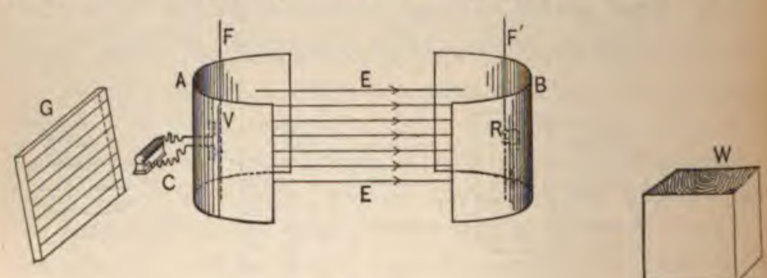


FIG. 110.

parabolic mirrors; V is a vibrator and R a resonator placed vertically in the focal lines F and F' of their respective mirrors; C is an induction-coil for charging the vibrator V. In fact the apparatus is a reproduction of parts of Figs. 76 and 77. When a spark passes in V, the resulting electric oscillations

send out a series of electromagnetic waves which are reflected from the zinc-faced mirror A, and thence proceed in parallel rays E, toward the similar mirror B, there to be reflected again and brought into convergence upon R, whence, if the mirrors be placed as in Fig. 110, with both focal lines parallel, a responsive spark will occur in R. Now, if the mirror B be gradually turned round an axis parallel to the direction of the rays E, the responsive sparks will become fewer, and cease altogether when the focal lines F and F' are at right angles to each other, even if the mirrors be moved close together.

Evidently, the rays E had been polarized by *reflection* at the mirror A.

To show this in another way: a large grating G was prepared by stretching thin wire in parallel lines from side to side of a frame; the mirrors were turned with their focal lines vertical and parallel; the wire frame was placed between the mirrors, perpendicularly to the direction of the rays E, with the wires in a definite direction relative to that of the focal lines of the mirrors. Thus arranged, the responsive sparks passed unabated in R; but when the direction of the wires was slowly changed by revolving the frame, then the sparks began to fade, and ceased entirely when the angle through which it was turned became 90°.

This is the exact analogue of the polarization of light illustrated with tourmaline plates in Figs. 99 to 102.

Again: in Fig. 108, when two Nicol prisms are "crossed" as at A and C, none of the polarized light which leaves A will pass through C; but if a crystalline plate be suitably interposed between the "crossed" Nicols, its axis making an angle of 45° with their long diagonals, this plate then resolves the ray into two components as in Fig. 92, and one of these finds an open way through the second Nicol: similarly, and for the same reason, when the direction of the wires in the frame makes an angle of 45° with the focal lines (the latter

being "crossed" or at right angles to each other), then sparks occurred in *R* in response to primary ones in *V*.

This was further illustrated by means of a block of wood: placed between the "crossed" mirrors, with the direction of its grain making an angle of 45° with the focal lines, it acted exactly like the crystalline plate between the "crossed" Nicols—resolved the rays as in Fig. 92, and thus *one* component reached the second mirror parallel to *its* focal line, and was concentrated on the resonator *R*, causing it to respond with a spark. The fibre of the wood was to the electromagnetic waves what the peculiar crystallization of the plate placed between the Nicol prisms was to those waves of ether that produce light.

Section Six: The Absorption of Waves.

58. Periodic motion, and the movement resulting from accord of period of two bodies.—Absorption may be said to result from a sympathetic movement, or identity of period, of two bodies.

Many things in nature have a definite period of vibration: a pendulum swings to and fro in a certain time dependent on its length; a piano-wire has a specific rate of vibration due to its length, weight, and tension; an organ-pipe will give out any note by varying its height; a vessel of water carried on the head may be caused to overflow by suitably timing the steps of the carrier; and the stout framework of a bridge may be sundered by the measured tread of an army.

If two clocks whose pendulums are the same length, be set up against a wall at a little distance apart, and one set going, the other remaining stopped, this latter, after a time, will start, too; the repeated ticking is communicated through the wall as a periodic impulse, and, feeble though each be, their sum produces the movement.

It has been stated that a column of air in an organ-pipe gives a musical note dependent on its length: place such a pipe over the flame of a gas-burner, and pitch the voice to the period of the tube, the flame will burst into song; silence the flame, and sound the same note on a musical instrument, again the flame will sing; even one singing flame will start another flame into unison with itself when covered by a tube like its own; but none of these effects will be produced by any other note than the one proper to the tube. It is the successive waves of air from the voice, instrument, or active flame, that, falling upon the quiescent one, cause it to flicker regularly and start similar waves in the column of air over it to produce the responsive note. Similarly, two tuning-forks of the same pitch placed on their sounding-boxes a little distance apart, if one be thrown into vibration and then stopped, it will be found that the other, which had not been touched, is sounding the note of the first: if either be loaded with a piece of wax, this destroys their identity of pitch and there will be no interaction whatever.

In like manner, if a person sings loudly into an open piano, the same note is gently returned by those strings which, if struck by the keys, would give out that note. And to carry the illustration further, if a series of tuning-forks, all of different pitch, be set upon a sounding-board, and a composite wave of sound—the finale of an orchestra, for instance—sweep through them, it will be sifted in the passage; each fork will pick out—*absorb*, those vibrations it would give itself, if struck, and only those will pass on that find no fork attuned to them.

It is the same with waves of ether: they reach us of every form and of varied length from their great central source—the Sun; they all strike upon the particles of matter; some find one kind of atom attuned to their wave-length—some another, and accordingly this matter gives out heat, or light of every hue, or is shattered into its chemical constituents to form new

combinations, or is electrified, or magnetized. And hence it is that some substances are transparent—others opaque; some, good conductors of heat and electricity—others, so bad, as to be called insulators; some, so sensitive to the actinic wave as to be decomposed by its slightest ripple—others, so stable that only the most violent shocks will disrupt them; some, easily receptive of magnetism—others, resistent to a degree that is next to utter exclusion. It is all a question of accord or discord between the vibrations of the atoms and the ether-waves that beat upon them. Glass is transparent to light-waves, though differing in length, while it is opaque to the longer waves of obscure heat as well as to the shorter ones that act chemically; a solution of iodine, on the other hand, is impenetrable to light, while giving free passage to obscure heat; and rock salt transmits both heat and light equally well.

If a red ribbon be held in the red portion of the solar spectrum, its color will be intensified; if in the green, or blue, or any other part, it will appear black; if a green ribbon be held in the green of the spectrum, it will be a brighter green, but in the red or blue it will be black: red and green are complementary colors, that is, one allows those waves to pass that the other absorbs, hence both absorb *all* the waves, and if used together, they constitute as opaque an obstacle to light as a plate of iron. A black ribbon absorbs all the visual waves just as red and green ribbons do jointly.

It is the waves that are reflected back to the eye that give the substance its color: those that are absorbed, augment the molecular vibration of the body which then feels warmer to the touch, as when the red, or the green, or the black ribbon is placed in the spectrum; or else these absorbed waves are stored energy, like a wound-up watch, to become apparent as phosphorescence or fluorescence at some future time; or they do chemical work, as when the carbon is torn from the

oxygen of carbonic acid, to form the woody structure of plants.

But a substance must have some thickness in order to quench enough waves to give it color: a thin stratum of ale is as colorless as distilled water, whereas a glassful has an amber hue, and water some feet in depth acquires a bluish-green tint.

A violet is blue because it absorbs all the longer waves of composite light and a geranium is red because it absorbs all the shorter ones, both species of flower reflecting to the eye those waves that give it distinctive color. But the blue of the sky is not due to absorption, but to reflexion—by the infinitesimal motes of distant space which turn back upon our eyes the short blue waves; while the crimson glow of morning and evening is transmitted light, the long red waves—the short ones being dissipated in atmospheric regions as a succession of rebounding echoes.

Thus every substance has a preference in the exercise of its absorptive powers, selecting some waves and rejecting others; as before stated, it is a matter of accord or discord between the wave and the molecules of the substance, just as in the case of the swing and the timid impulses to it, or the tuning-fork responsive to one of like pitch in vibration.

59. Spectrum analysis and the absorption of light waves. — By suitable means, every substance may be reduced to a state of vapor; sulphuric ether volatilizes in air, water becomes steam at 212°, and brass is converted into a gaseous body in the electric arc. As a vapor, the molecules of a substance enjoy great freedom of movement—they spread throughout space, or draw together under any pressure; they dart back and forth in every possible direction, colliding, recoiling, shooting on again through open vistas, or bombarding the walls of the containing vessel. But a vapor is only the minute subdivision of a substance—it is composed of molecules, and these of atoms: the molecule of water consists

of atoms of oxygen and hydrogen; that of brass, atoms of zinc and copper; and that of ether, carbon, oxygen, hydrogen, and sulphur. The atoms are the elements of matter that admit of no further subdivision or simplification; they are probably of different sizes and undoubtedly of different weights—the dense platinum cannot be of the same atomic weight as the light aluminum or still lighter hydrogen.

Whether wholly free from other atoms, or chemically bound to one or several, each atom has its own proper vibration, differing in period and character from that of every other atom.

Between atoms chemically combined there are two influences—one, vibration, urging them apart, the other, attraction, drawing them into closer union, and the balance of these constitutes the stability of the molecule. Whatever destroys this balance, decomposes the molecule and sets its atoms free to form new combinations—a chemical reaction. Suppose a flood of sunlight to stream into a vaporous mass: it is not a simple billow, but a complex host of waves of varied size and length travelling on, commingled; among them there are some whose periods coincide with the vibration of some of the atoms—they fall upon such atoms as timed impulses and eventually swing them free from their partners.

One can easily imagine, for instance, the quick, short waves beating upon the light atoms of oxygen and hydrogen in sulphuric ether, and imparting to them such violent motion that they pass beyond the limit of attraction and are thus rent entirely from the heavy sulphur and carbon.

It is like a succession of moderate waves sweeping the deck of a ship: they do not much disturb the hull itself, but small articles in their course are carried further and further by each wave until finally they are washed overboard—and the lightest go first.

The sunlight flooding the vaporous mass is like a compound wave of sound flowing through an assemblage of tun-

ing-forks—each atom picks out its sympathetic wave just as the fork does its own musical note. And this accord between ether-waves and atoms results in absorption of wave-motion.

The same is true of Light, and indeed it forms the basis of Spectrum Analysis which thus becomes pre-eminently an example of the absorption of wave-motion. Every atom being in a state of vibration, the result is, that the great ocean of ether in which all matter is embedded, is forever surging with waves of different lengths; the period of vibration is peculiar to the kind of atom, and that of one element differs from every other—sodium from carbon, silver from iron, nitrogen from chlorine. Upon the period of vibration depends the wave-length, and upon this the sensation of color it produces, so that each kind of atom, when intensely heated in a state of vapor, sends out waves of one or more definite lengths, which invariably produce the single color or group of colors proper to those wave-lengths, just as a tuning-fork emits a definite note, or one with its harmonics.

In free ether, waves of all lengths travel with the same velocity, but on entering matter they are variously retarded. This difference in retardation—in reality, refraction—affords a means of separating the commingled waves by passing them through a prism.

Fig. 111 illustrates the apparatus used by physicists to perform the experiments upon which the foregoing statements are based: *A* and *A'* are the carbons of an electric arc-light placed within a camera; *B* is a lamp capable of giving a very intense flame; *E*, a lens; and *P*, a prism. First, conceive everything removed except the camera itself; then the light issuing from its aperture *L*, encountering neither lamp, lens, nor prism in its path, will fall directly upon a screen at *F*. Place a bit of silver in the hollow of the lower carbon and draw down the upper one until the current spans them: soon the silver will be reduced to a vapor that streams from the lower to the upper carbon in an arc that forms a

characteristic bright lines of the potassium vaporized in the flame. And the experiment might be continued with every elementary substance with similar results; and to such extent that if all the elements were vaporized together in the lamp, the brilliant spectrum from the arc-light would be furrowed by an infinity of black lines, and these, if the camera were removed and the arc-light spectrum thereby suppressed, would flash out into brilliant colors—the characteristic indices of the incandescent vapors.

The deduction is inevitable: the atoms of vapor in the lamp were vibrating in certain periods; the waves of ether sent out by the white-hot carbons were of every possible length; some coincided in period with the atoms and were absorbed by them, just as the pendulum absorbs the timed impulses given it; and these absorbed waves left void spaces which appeared as black lines in the brilliant spectrum formed by the remaining waves from the carbons which passed on without interruption. But if the vapor in the lamp be so hot that it emits more intense waves than it absorbs from the carbon source, its lines on the spectrum will be brighter than the region of color in which they fall; if the emission and absorption are equal, no change will be apparent in the spectrum; while it is only when the vapor emits fewer waves than it absorbs that the black lines appear.

The spectrum of the Sun is full of black lines: by successively projecting beside it, by suitable means, the spectra of different metals, their bright lines coincide exactly in position with certain of these black solar lines. As it has just been shown that colored lines can be produced only by definite waves, and that the absence of these waves leave black spaces where the bright lines were, hence it is inferred that a similar state of affairs exists in the Sun as with the arc-light and the vapor in the lamp-flame.

The Sun consists of a white-hot mass within a rind of vapor: the core alone would give a brilliant spectrum with-

out any black lines, but its light having to pass through the vapor, is shorn of certain waves—the atoms of the vapor absorb more waves than they emit—and hence the black lines in every solar spectrum; on the other hand, the surrounding peel, free from the core, would give the characteristic bright lines of all the metallic vapors that form it. Thus does the material of not only the Sun but of the most distant stars become known by means of their spectra; and the underlying principle of this extensive analysis is absorption of wave-motion—accord between atom and wave.

The foregoing are the salient features of spectrum analysis, and while they suffice for the object in view, namely, to illustrate the absorption of wave-motion, still they afford but a partial view of the subject; it is not so simple as the statements made would imply, and, to present it more definitely, a few of the complexities must now be mentioned.

"Nearly twenty years' work has brought perfect harmony between laboratory, solar, and stellar phenomena. It has proved beyond all question that not only are both fluted spectra and line-spectra visible in the case of most of the elements, but that many of the metallic elements have at least two sets of lines accompanying, if not resulting from, the action of widely differing temperatures. . . . The different chemical elements behave very differently in regard to the action of heat and electricity upon them as we pass from the solid to the liquid and vaporous forms. . . . In the cases in which heat-energy can go so far, we first get an increase in the free path of the molecules, and ultimately the latter are made to vibrate. In the case of electricity, increase of free path is scarcely involved, and hence we may have effects similar to those produced by high temperature, with scarcely perceptible effects of heat in the ordinary sense. . . . We now know that many elements present changes at several widely differing stages of heat. The line-spectra of elements like sodium, lithium, and others may be obtained by the heat

of the flame of a spirit-lamp, or a Bunsen's burner. This temperature has no effect upon iron and similar metals: to get any spectral indications from them, a higher temperature—the blow-pipe flame—must be resorted to. We get in this way what is called a 'flame-spectrum,' in which flutings and some lines are seen. In order to obtain the complete line-spectra of some of the less volatile metals, like iron and copper, we are driven to use electrical energy and employ the voltaic current and metallic poles which are so strongly heated by the passage of the current that the vapor of the metal thus experimented on is produced and rendered incandescent. We may say generally that no amount of heat-energy will render visible the spectra of gases. These are obtained by enclosing the gases in glass tubes and illuminating them by means of an electric current: the ordinary voltaic current used in laboratories is equally inoperative. We must have the induced current, and with different tensions, different spectra are produced. Heat-energy, which does give us line-spectra in some cases when metals are concerned, fails us in the case of permanent gases and many metals. A voltaic current gives us spectra when metals are in question, but, like heat-energy, it will not set the particles of the permanent gases vibrating. But when both metals and the permanent gases are subjected to a strong induced current—that is, a current of high tension when an induction-coil with Leyden jars and an air-break are employed, we get this vibration; gases now become luminous, a distinct change in the spectra of the metals is observed, a change as well marked, or perhaps better marked, than any of the previous lower temperature changes. When the tension is still further increased, the differences in the spectra are most marked in the case of gases, for the reason that being enclosed in tubes, they cannot escape from the action of the current. . . . The individuality of the various chemical elements comes out in a remarkable manner. To take one or two instances: Hydro-

gen gives us what is termed a structure-spectrum, a spectrum full of lines; this changes to a series. Oxygen gives us series which change into a complicated line-spectrum in which no series has been traced. Nitrogen gives us a fluted spectrum which changes into a complicated line-spectrum. In the case of magnesium, iron, and calcium the changes observed on passing from the temperature of the arc to that of the spark have been minutely observed. In each, new lines are added or old ones are intensified at the higher temperature. Such lines have been termed *enhanced lines*. . . . The enhanced lines are very few in number as compared with those seen at the temperature of the arc. In the case of iron, thousands are reduced to tens. If we include the non-metals, more stages of temperature are required, and it then becomes evident that different kinds of spectra are produced at the same temperature in the case of different elements; in other words, at many different heat-levels changes occur, always in one direction but differing widely for different substances at the lower temperatures. At the highest temperatures—at the limit, there is much greater constancy in the phenomena observed, if we disregard the question of series. . . . Photographs of the *enhanced lines* have been obtained by the use of a large induction-coil, giving a 40-inch spark. . . .

"The way in which the enhanced lines have been used, is as follows: Those belonging to some of the chief metallic elements have been brought together, and thus form what I have termed a 'test-spectrum.' This has been treated as if it were the spectrum of an unknown element and it has been compared with the various spectra presented by the Sun and Stars.

"I may here say that the test-spectrum turns out to be practically the spectrum of the chromosphere; that is, the spectrum of the hottest part of the Sun that we can get at, and that a star has been found in which it exists almost alone, nearly all the lines of which had previously been regarded

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All this body of evidence required a recasting of the conceptions of elementary substances. The original idea—one spectrum for each substance—pointed to a distinct individuality for each chemical element; but the new analysis indicates nothing less than an assault upon this position.

I have nowhere seen an explicit statement of the dissociation doctrine, but if I infer it aright from stray hints, it is this: that there is only *one* primordial substance; that at successive stages of coolness particles of this *associate* to form the various chemical elements we now consider the primaries of nature; and that when heat or some other form of energy is applied to a complex substance, it gradually becomes simpler —*dissociation* of the particles takes place, until at the highest limit of the energy at our command, the simplicity of the spectrum attained is an index of the primitive condition of matter. To illustrate, consider a compound of several substances—sodium, sulphur, tin, lead, aluminium, and copper: apply heat to the mass; sodium melts first, at 90° C., then sulphur at 114°, next tin at 232°, lead follows at 326°, eventually aluminium at 654°, and finally copper at 1081°; vaporization of each follows also a gradation of heat, and it is evident that the spectrum of the compound changes as the gases of the different elements are thrown into a state of vibration, or as the substance becomes less complex—as *dissociation* progresses.

On reversing the process—cooling—the particles recombine in differing numbers and variety of structure to form the original elements of the compound.

The nebular theory of the universe is, that originally all matter was evenly diffused throughout space in small particles—as vapory masses or nubulæ, and that successive aggregations of this formed Sun, stars, and planets.

"The spectroscope found among celestial objects some

which were truly clouds of incandescent gas: . . . these gaseous clouds were of the simplest composition; hydrogen and nitrogen were their chief constituents; how, then, could a world like ours originate from them? . . . From nebula to planet there is a regular, progressive order of chemical complexity. The nebulæ are simple; in the hotter stars a few more elements appear; more still can be detected in colored stars and the Sun; but the planets, represented by our Earth, are most complex of all.

"So far the facts; the scientific imagination now comes into play.

"If suns and planets were derived by a process of condensation from such nebulæ as exist to-day, perhaps the process of evolution was attended by an evolution of the chemical elements themselves. Upon that supposition the facts become intelligible; without it the evidence is not easily coördinated. This hint, together with the suggestions offered by the periodic law, has made chemists more ready to consider the probable unity of matter, even though actual proof for or against the conception has not yet been attained. That the chemical elements are absolute and final few thinkers of to-day believe; the drift of opinion is mainly in one direction, but no element has yet been decomposed or transmuted into another." (Prof. F. W. Clarke.)

60. Absorption of electromagnetic waves.—Substances have the power of selective absorption and to it is due their color. A brick wall or mass of pitch absorbs all light-waves, but offers no obstacle to the electric ray; while a sheet of water transmits light, but bars the passage to all electric waves—absorbs them.

The discharge of a Leyden jar is a surging back and forth between the knobs, as has been experimentally proved by reducing the frequency of oscillation within the limits of both vision and audibility.

A tiny jar heavily charged will give very rapid surgings;

but by enlarging the jar and lengthening the circuit the oscillations become slower: by this means they have been slowed down to such number as to produce a musical note, and while this was sounding, a mirror suitably revolved, exhibited the passing sparks as a serrated band of light just like that afforded by a singing flame. Each spark causes a sudden thrust of heat, as it were, into the air, and being periodic, there is a consequent rarefaction and compression—a wave-motion of the air—which causes the musical sound. At the same time the surging from knob to knob sends out waves into the ether—electromagnetic waves—which are prone to excite movement in any body susceptible to their action and whose period of oscillation corresponds to their own.

If this body be another Leyden jar attuned to the discharging one, the waves falling upon it (like waves of air from a violin upon a sympathetic piano-wire) will excite surgings in it until their accumulated force bursts forth as a spark—the visible evidence of the absorption of electric waves. If this second jar be thrown out of harmony with the first, by varying its size or the length of the circuit, it will no longer respond; so that the effect is wholly due to accord between jar and jar, and hence necessarily between jar and wave, and thus it reduces, as in the case of heat, light, and chemical action, to absorption of wave-motion.

61. **Absorption of magnetic waves.**—Suppose a large bar-magnet to be suspended by a fine wire attached to its center of gravity, and provided with a sliding weight for counteracting the natural dip of the locality: when this weight is adjusted, the magnet will hang so quietly that the unaided eye will scarcely perceive its small motion. Now at the distance of several feet hold another powerful magnet and move it to and fro in the direction of the suspended one; this will begin to move, and by harmonizing the motion of the hand with that of the suspended magnet, the latter will soon acquire oscillatory movement over a large arc.

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gaseous clouds were of the simplest compo
and nitrogen were their chief constituents;
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which this Treatise is most concerned, for they are
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hip around the compass-needle.

other hand, there is a rotary magnetic effect sur-
every wire carrying a current, while extending out
angles to it there is a wave-motion with every varia-
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r-waves that produce light and heat may be excited
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62. Absorptio...
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Varied experiment has established the following facts: That Hertz waves have essentially the same velocity in air as along wires, it being in all cases equal to the velocity of light; that throughout the region pervaded by them the electric and magnetic forces are complementary, that is, where one is a maximum the other is a minimum; that the lines of these forces are at right angles to each other, the electric component being parallel to the axis of the oscillator; and that the indices of refraction for substances opaque to light may be determined by Hertz waves.

In the apparatus to be described, the "spiral-spring receiver" acts the part of a *coherer* in wireless telegraphy, that is, closes the circuit when the Hertz wave sweeps through it and thus enables the voltaic cell to perform the principal part, namely, send a current through the galvanometer.

Plate A presents a view of the apparatus arranged for experiment with several articles used for different purposes: *R* is the radiator; *T*, tapping-key; *S*, spectrometer circle; *M*, plane mirror; *F*, collecting-funnel attached to spiral-spring receiver; *t*, tangent screw by which the receiver is rotated; *G*, galvanometer; *B*, circular rheostat; *V*, voltaic cell; *C*, cylindrical mirror; *A*, totally reflecting prism; *P*, semi-cylinders; and *K*, crystal holder.

Fig. 112 exhibits the radiator *R* of Plate A: it consists of a ball *b* and two beads *ee'*, all platinum; the beads are attached to jointed stems forming the electrodes which are connected with a small induction-coil actuated by a storage-cell. The shortest wave-length produced was of a frequency which is about thirteen octaves below visible radiation, or light. The condenser consists of paraffined paper with tin-foil on both sides, wound spirally; this, the storage-cell, induction-coil, and an interrupting key are all enclosed in a tin box placed inside a copper one, Fig. 113. The two metal boxes prevent stray radiation. Pressing the interrupting key at the side produces a flash between the beads *ee'* and ball *b*, whence elec-

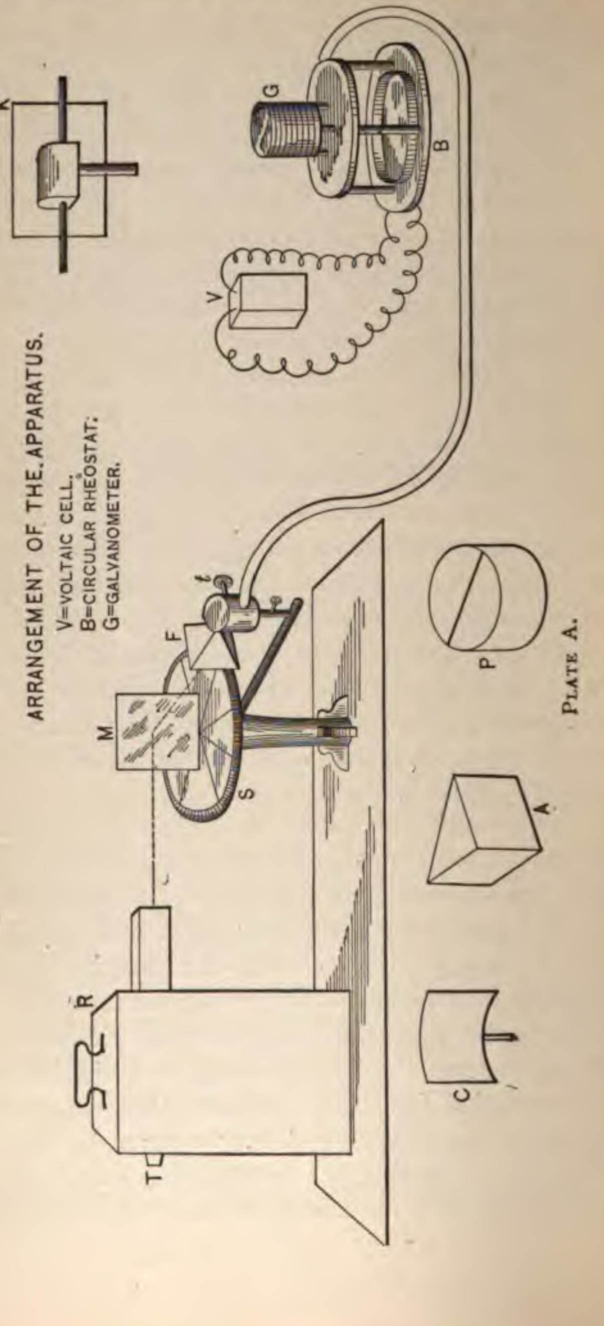
ARRANGEMENT OF THE. APPARATUS.
V=VOLTAIC CELL.
B=CIRCULAR RHEOSTAT.
G=GALVANOMETER.
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PLATE A.

nagnetic radiation streams forth into space from the tube
ront of the box.

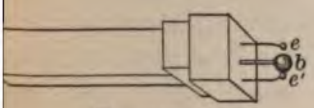

FIG. 112.

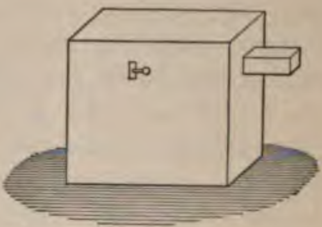

FIG. 113.

Fig. 114 represents the Receiver to which the funnel *F*
Plate A is attached: as already stated, it is on the coherer
nciple—spiral steel springs being laid side by side in a nar-

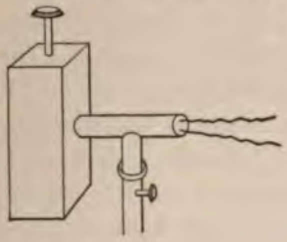

FIG. 114.

groove between brass pieces in connection with project-
metallic rods which serve as electrodes.

The receiving circuit, then, consists of this spring coherer
series with a voltaic cell and a dead-beat galvanometer.
electric current enters by the upper spiral and departs by
lower one, having to traverse the intermediate spirals
ng the numerous points of contact. The resistance of the
eiving circuit is thus almost entirely concentrated in the
sitive contact surface: When electric radiation is absorbed
this surface (the Hertz wave sweeping through it) the re-
ance is reduced, the voltaic current acts and the galvano-
ter spot-of-light is violently deflected; by variously com-

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For *circular reflexion,* the curved mirror C is substituted for M, and placed at the distance of its radius from the spark; the reflected image will be at an equal distance, and the receiver is to be set there; when it responds, it will be found that the index bisects the angle between the directions of the radiator and receiver.

For *total reflexion,* the receiver is placed opposite the radiator, and the prism A interposed with one of its equal faces at right angles to the direction of radiation; the receiver remains unaffected until suitably turned, when it responds to the totally reflected ray.

For *refraction,* an isosceles right-angled prism of sulphur or ebonite is used with a parallel beam of electrical radiation; to cause deviation of the beam, one of the acute angles of the prism is interposed in its path.

Opacity, due to multiple reflexion and refraction, is analogous to the like effect produced by powdered glass on light: it is shown by filling a long trough with irregular pieces of pitch and placing it between the radiator and receiver; the electric ray is unable to pass through the heterogeneous media, owing to the multiplicity of reflexions and refractions, and the receiver remains unaffected; but by restoring partial homogeneity by pouring in kerosene which has about the same refractive index as pitch, the radiation is easily transmitted.

The *indices of refraction* (electric) for various substances opaque to light are determined in precisely the same way that they are for light.

Interference experiments consisted in determining wavelength (electric) by means of gratings.

For *polarization and double refraction,* the apparatus of Plate A is modified and arranged as shown in Fig. 115: A is the radiator; E, the receiver to which the collecting-funnel F is attached; D, a vertical graduated disc by which the rota-

tion is measured; *K*, a crystal holder; *S*, a p
rock; *C*, a crystal; *J*, a jute polarizer; *W*
polarizer. The cylindrical lens is used to pr
beam, and at its end is a slot into which to
The crystal holder *K* is fitted at the end of t
ing the lens, and is capable of rotation round
to the direction of the ray. The receiver a

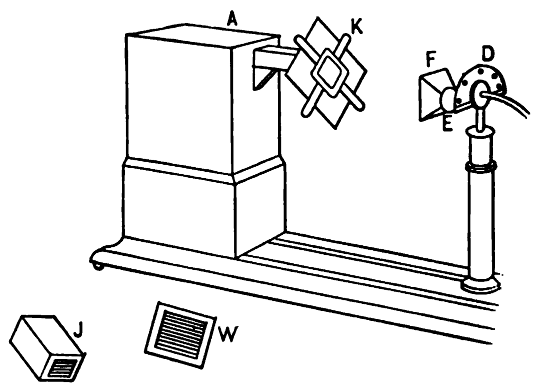

FIG. 115.

rotation round a horizontal axis by m
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by winding fine copper wire on squ
with parallel slits cut in them, a sul
and jute are all alike used as polariz

The analyzer is fitted on the r
positions: first, parallel, both g
second, crossed, polarizer horizo
the first, radiation is transmitted
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dark.

But on interposing crystals

45° to the horizon, the field is partly restored and the spot of light sweeps across the scale: many crystals produce this effect the same as they do for light; tourmaline, so in a marked degree. Vegetable fibrous substances do the same —jute in particular.

CHAPTER V.

FACTS THAT LINK THE VARIOUS FORMS OF RADIANT ENERGY ONE TO ANOTHER—A CHAIN OF MOTION.

Section One: Analogous Effects of Waves of Air and Ether.

64. In the preceding chapter the phases of wave-motion described constitute the great arteries that permeate all the phenomena alike; but there are lesser veins, common to two or three, which are worthy of mention, because they tend to weld the kinship of all the phases of radiant energy: if we can tie heat to light, and by another bond unite this to electricity, and by still another connect the latter with magnetism, we strengthen the evidence in favor of electricity and magnetism being motions of the ether, and that many of those motions are purely waves.

When a wave breaks upon a rock, it does not pass on in straight lines, leaving smooth water behind the rock, but bends round it in swirling eddies; when a house stands between us and a source of sound, we can still hear around its corners; and when a beam of light is broken by a screen, it is not divided by a clear-cut line, but there are umbra and penumbra—graded intensity of sound as well as deepening shadow for light: this bending of *waves* round obstacles in their path is a feature common to *all* wave-motion.

65. The approach and recession of sources of sound and light produce analogous effects.—The *pitch* of a musical note is dependent upon the number of vibrations of its source per second, and this indirectly determines the length of the wave that produces the note. As a train approaches a station, the whistle of the engine becomes more shrill—as it passes beyond, more grave: in the former case the frequency is greater and the waves are shortened, as they fall upon the ear of a listener at the station; and in the latter the frequency is less, and the waves are lengthened.

This being a peculiarity of wave-motion, a similar effect should be found in light; for color is to light what pitch is to sound—a result of wave-length.

In the article on Spectrum Analysis, it has been seen that the chemical elements give distinctive spectra at specific stages of thermal or electrical energy, and that comparison of these spectra with those of the Sun and stars, has established the fact that the heavenly bodies are composed of the same substances as the Earth.

Primarily, the vibrations of the particles of a substance create waves in the ether, which, striking the eye, cause the sensation of light—color, according to their length, and intensity, according to their amplitude, just as pitch and loudness of sound are due to the frequency and amplitude of air-waves: therefore, like the change of pitch from the whistle of the engine, if a source of light approaches or recedes rapidly enough, its color will change because of the variation in the frequency or length of the waves striking the eye in a second. Glowing sodium vapor, for instance, gives a brilliant yellow band at a certain temperature, due to its atomic vibrations; these are invariable, but if the glowing mass be moved away rapidly enough, the waves it excites in the ether would be lengthened and a reddish tint, the analogue of a graver sound, would result; if, on the contrary,

it were brought near, the waves would be shortened, giving a greenish hue, as the whistle gave a shriller note.

Now, by actual comparison of the blue-green *F* line in the spectrum of Sirius with the blue-green line of the spectrum of hydrogen contained in a tube, the former was found to have moved toward the red to such extent as to indicate (when the necessary calculations were made), that Sirius was receding from the Earth about thirty miles a second.

66. Velocity of waves in air and ether, and analogy in the sensations of sound and light.—A tuning-fork in vibration sends out waves in the air and the discharge of a Leyden jar does the same in the ether; and however varied those in either medium may be, all waves of air have one velocity—that of sound, and all of ether, another—that of light; and if the waves of both are mingled, as when musical vibrations are discharged into a gas flame, the latter will present a serrated appearance, Fig. 116, characteristic of the notes in the combination—a visible exhibit of what Fourier's series ex-

FIG. 116.

presses mathematically: or, again, if the waves do not produce harmonious strains, but are full of "beats"—harsh and rasping to the ear, the light will be equally disagreeable to the eye by its irregular flickering.

67. Waves of air and ether in the telephone circuit.—A telephone circuit affords an instance of electromagnetic

rising from the action of waves of air: a thin metal the transmitter moves to the impulses of a speaker's miles away, a similar plate in a receiver pours into the s ear those same impulses with such exactness that e voice is recognized. Every one knows that it is not f *air* that fill the interval, as when two persons speak other a few feet apart, and every one equally well that it is some *motion* along the connecting wire, by the changing magnetic field at each end, that pro- e effect; the *nature* of that motion is the point sought made clear—it is *wave*-motion; for waves of air go telephone at one end and waves of air come out of it ther, and no bridge of *air*-waves spans the chasm—it of *ether*—electromagnetic waves.

A glass rod when rubbed emits a musical note— a steel bar when violently magnetized.—If a glass rubbed, it is thrown into vibration which gives rise to cal note, Fig. 117, and if the friction be vigorous

FIG. 117.

FIG. 118.

the vibrations will at length shatter the glass into sections, Fig. 118: similarly, if a steel rod be *sud-*

it were brought near, the waves would be shortene
a greenish hue, as the whistle gave a shriller note.

Now, by actual comparison of the blue-green *F*
spectrum of Sirius with the blue-green line of th
of hydrogen contained in a tube, the former wa
have moved toward the red to such extent as
(when the necessary calculations were made), th
receding from the Earth about thirty miles a se

66. Velocity of waves in air and ether, a
the sensations of sound and light.—A tunin
tion sends out waves in the air and the dischar
jar does the same in the ether; and however
either medium may be, all waves of air hav
that of sound, and all of ether, another—t
if the waves of both are mingled, as when
are discharged into a gas flame, the latter
rated appearance, Fig. 116, characteristic
combination—a visible exhibit of what

A
B
C

FIG. 116.

presses mathematically: or, again
duce harmonious strains, but are
rasping to the ear, the light will
the eye by its irregular flickerin

67. Waves of air and ether
A telephone circuit affords an

..me is
·tween

lectrified,
nded by a
ted tourma-
ever, still like
two poles.
tablished, it will
ch are they alike,
get each other and
almost all conditions
ed near a coil of wire
flowing round a spiral
d in its axis into a per-
ricity exists in the kinetic
m a kind of whirling at-

ht **and sound.**—Throughout
s been frequent comparison of
it was the striking resemblance
it first led to the theory that light
nedium, as sound is to waves of air.
are facts whose existence has been
ntal proof, while the ether and its
ith hypothesis. But the undulatory
ny phenomena of light, and connects
a harmonious whole, that it carries to
only less forcible than that of experi-

denly and *powerfully* magnetized.
while undergoing the process; n.
give a musical sound, therefor
thrown into vibration to cause
also, the magnetic action is a
and perhaps if it could be m
shiver the steel into visible m
was rent into sonorous discs.

Section Two: Varied Ties betv
Mag

69. Heat and light.—
equally with its dazzling li
from a copper shell filled w
brilliance emanating fro
polarization, and by the sa
plane, circular, or ellipt
polyed. Indeed so intin
and light—so much like
one into the other, that
feasible with the other:
heat-rays would produ
moreover, if mixed in
by a solution of iodine

70. Minor relatio
magnetism.—The tie
by the fact that meta
number that denotes
tricity is almost iden
behave alike: the fl
the other to differen

In experiments
crossed, thus barri

...ture of Substances.

...ances on wave-motion.
...marked effect upon its
...t, electricity, and mag-
... of air—in precisely the
... four others—waves of
... to illustrate further the

...at is of uniform texture
. point: if heated, all its
...f struck, all sound-waves
...he effect will pass onward
...n every direction. Com-
...ood is not; this is a type of
...ertain directions called axes
... ss it, and round the rings of

...19.

... varies greatly in these direc-
... conductivity of sound and heat,
... along the axis of greatest elastic-

... out of its natural shape by any
... an effort of the molecules—
... that this plays an important part
... motion is shown by the fact that
... n three metals—lead, silver, and
... varies accordingly, being twice

eat in silver as in lead, and twice as great in steel as in

. **Crystallization the prevailing structural form of ances.**—Most substances are not haphazard agglomera- of matter, but structures of great symmetry and design of some primary form called a crystal.

hese are of varied shape, but six distinct classes have made, based on the number and direction of the axes raverse them.

round the same axes, however, a great variety of figures be formed. It must be understood that there are no traces of the axes of a crystal—they are imaginary lines nmetry which describe and classify the body.

igs. 120 to 125 represent the six primary forms of crys- nd the extent to which the architecture of nature is com-

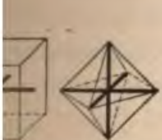

FIG. 120.

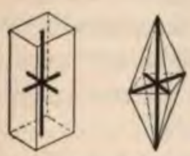

FIG. 121.

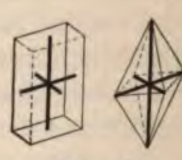

FIG. 122.

l of crystalline forms may be seen in any museum of al history: metals, rocks, and precious stones in end- number and variety will there be found so built up.

FIG. 123.

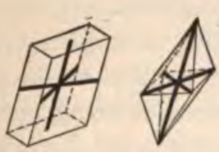

FIG. 124.

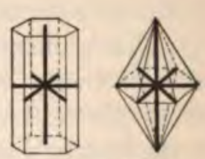

FIG. 125.

ity is the motive of their formation—the cement that s molecule to molecule until we have the flashing dia- l or the everlasting granite.

paper over a magnet, and
article joins itself, end-on,
rned along a line of force:
ation of the frosted tracery
ne meets on the pavement
. also, a solution of alum,
pane of glass, will leave, on
culiar crystalline structure
g within the range of their
shown, the dark lines repre-

cipal directions of open and
along it—so numerous crys-
s of differing density. Those
e direction, and of a different
t right angles thereto, are said
axial, and such is Iceland spar:
o axes of uniform density, with
s at right angles to them, are

density of substances on wave-
avel faster in the dense directions
e molecules are more separated;
oo, find the path of density a line
her—the gaps are smaller and the
stic molecules pass on the motion
ore facility.
smuth, which conducts both heat
lel to its planes of cleavage than
s being more intimately connected
tter direction.
be subjected to strain or pressure,
ave motion equally well in all direc-
d it exactly like a body of variable

density; and a return of the glass to its uniform condition, brings back its former action on wave-motion: this brings out the fact that it is the difference of density of a substance in different directions that facilitates or retards the waves, and also that the action is primarily molecular, for greater or less density means a more or less close grouping of the atoms of a substance.

75. Distinctive colored figures produced by crystals and polarized light.—The matter just treated, leads to a similarity between some phenomena of polarized light and magnetism and electricity, that will now be dealt with. Consider Fig. 126: *B* is a beam of natural sunlight that enters a Nicol prism *P*, is there polarized, and emerges at *F* with oscillations in the vertical plane only; these are converted by the lens *L* into a conical beam *H* which falls from the crystal *C*; passing through this, it proceeds onward as another conical beam *K* symmetrical with *H*, and enters the Nicol prism *A*, to finally reach the eye at *E*. The kind of crystal at *C* determines the effect that will be perceived by the eye: if it is a uniaxial crystal cut perpendicular to the optic axis, an image like that at *R* will be seen—concentric rings of rainbow hues broken by a dark cross; if it is a biaxial crystal cut perpendicular to a line bisecting the angle formed by the axes, as in Fig. 128, the image at *O* will be seen—a series of variegated circles, ovals, and other curves about the ends of the axes, and broken as before by a black cross. To understand these effects, suppose the crystal to be Iceland spar of which Fig. 127 is a vertical section: it is double refracting, as previously explained; a ray *mn* passing through it in the direction of the optic axis, *vw*, will not be divided, but every other ray of the conical beam, such as *o*, *s*, etc., entering obliquely to the axis will suffer double refraction, and *two* rays *tt'* and *rr'* will emerge for every *one* that enters; they will be polarized in planes at right angles to each other. As this has been produced by difference of density of the prism in two directions, one series

of oscillations will be retarded over the other—they will be out of step—have a difference of phase whose amount will depend on the thickness *xz* of the prism. The optical axes

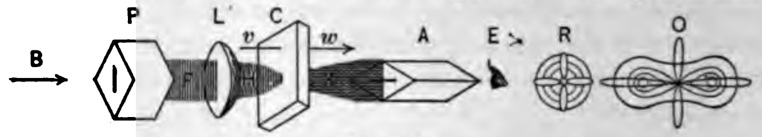

FIG. 126.

of the two Nicols *P* and *A* being at right angles to each other, it is evident that as no horizontal rays emerge from the polarizer *P*, and no vertical rays can pass through the analyzer

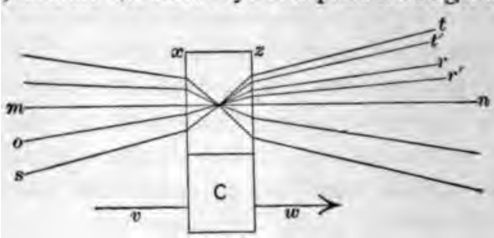

FIG. 127.

A, there will be no light to reach the eye in these two directions, which accounts for the black cross in the image. But all the other rays around the conical beam *K* entering *A* will

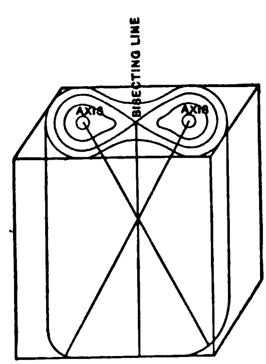

FIG. 128.

have their oscillations resolved into the horizontal and vertical directions as explained in a former article; the vertical

will be stopped by the position of *A*, but the horizontal will go through; being different in phase, however, they will interfere, and produce the colored rings of the image. And the image at *O* is produced in like manner by a nitre crystal. These effects are the result of polarized light alone, and not in any case of ordinary light. The coloring of the image is due to the crystalline nature of the plate at *C*, which decomposes the light as any prism would.

But that this image is composed of curves which differ with the crystal used is the fact that attention is directed to; with Iceland spar circles appear—with a plate of nitre, ovals, lemniscata and other forms: therefore the structure of the Iceland spar must differ from that of nitre, and moreover, that there are any curves at all, is due to a definite *structure* of the crystal as distinguished from a plate of indiscriminate aggregation. This can be demonstrated: substitute for the crystal at *C*, Fig. 126, a pane of common glass—a structureless body; it causes no double refraction, so that the vertically polarized beam *H* emerges from it just as it entered, but is stopped by *A* whose axis is horizontal; no image will be seen; but now spread a solution of nitre on the same glass, and when it has evaporated, leaving the crystalline structure of the nitre spread over the pane, place it at *C*, and immediately the same image will be seen that a plate of nitre itself would produce.

That a crystalline structure of definite form, acting upon waves of ether, throws them into a series of regular contours, and that the variegated hues of these can be deduced as a consequence of the undulatory theory of light—this is the central fact to be kept in view.

76. Identity of the figures produced by crystals on polarized light with the equipotential lines surrounding electric and magnetic foci.—If a sheet of paper be laid on the pole of a magnet set upright on a table, and iron filings be strewn on it, they will form filaments radiating from the

pole, as in Fig. 129; they delineate the magnetic field, whose intensity diminishes at a uniform rate from the pole: a series of circles, therefore, will represent the equipotential lines of this field. Contrast it with the optical effect at *R*, Fig. 126, and it will be seen that the resemblance is most striking.

FIG. 129.

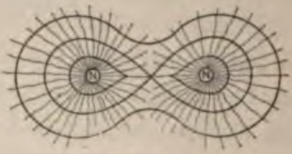

FIG. 130.

Again: let the sheet of paper be placed upon the like poles of two vertical magnets, as in Fig. 130, and spread the iron filings as before. The filaments will again be built up radially from each center, except in the space between the poles, where, being of like nature, they clash and try to force each other out of the field. The equipotential lines of this field are precisely the ovals, lemniscata, and other curves of the optical effect.

In every case, the curves of the optical effect are due to *interference* of the ether-waves; but it is not hence to be understood that the curves of the magnetic field result in the same way; they are merely the boundaries of equal potential surfaces, arbitrarily drawn, closely or far apart, as desired: the magnetic field is like a uniformly sloping lawn—the optical effect like a terraced declivity.

Before strewing the iron filings on the paper, nothing was seen—nothing felt—that distinguished the space around the poles from remote regions; but once that the iron particles showered down upon the paper, they were seized with avidity and forced into a visible and tangible structure of great regularity and strength: remove the magnets and in a flash this structure crumbles like a toy-house.

Now the magnet never touched the filings—a partition of

paper intervened—and yet it must have spread among those filings some powerful influence that wrought them into shapes whose contours were exactly those of the figures produced by crystals upon polarized light.

That the curves of Fig. 130 are characteristic of any two centers of force is further illustrated by terrestrial magnetism. Observe Chart I: it represents two views of the globe with equipotential lines of total magnetic intensity; around each pole or center is the figure of 8 with its exterior curves—irregular and long drawn out, to indicate prevailing conditions, but still distinctly the characteristic curves. Or, again, notice Chart IV—a Mercator's projection, on which is portrayed the horizontal component of the total force shown on Chart I: an egg-shaped form covers the region south of Mexico, and its corresponding oval spreads over the sea north of Australia; embracing these two areas of greatest intensity are lemniscata and other curves of much regularity, and this is the aspect, whether our view extends from the small oval eastward over the Atlantic and the continents of Europe, Asia, and Africa, or westward across the broad expanse of the Pacific.

Taking in at a glance the former view, so great is the resemblance of its curves to the figures upon the plane cutting the biaxial crystal of Fig. 128, that one might imagine the Earth a huge crystal of like kind whose axes protruded through the crust at Mexico and Borneo, and the bisecting line of their angle, reached the surface in mid-Atlantic at the apex of the lemniscata. These curves receive further illustration in Gauss' theory of terrestrial magnetism, of which a summary will be found in a later chapter.

Section Four: Ether Waves.

77. The ether alive with undulations, a
—Facts have been adduced to show that
theory is applicable, not only to light, but a
tricity, magnetism, and chemical action;
ether is full of undulations of every variety
is agitated by an infinity of waves: and al
produce different sounds, so do the former

The wave of air has an origin and a goa
ear, it simply travels on as wave-motion
sound: so, the ether-undulation produces
it falls upon matter, and the nature of this
greatly the character of the effect—one b
other, decomposed; a third, electrified
the eye is excited to light. It is because
predominates from certain classes of w
been divided into the thermal, luminou
the spectrum: the correct view, howe
not waves that produce heat alone, or
cal action only, or electromagnetic e
nearly all ether-waves, under suitable
ferent effects, yet that some produce
than another that it becomes a charac
sense we may justly speak of heat-w
waves, and electromagnetic waves-
of designating them by their salien

78. The "continuous" curren
—The electric current is a true
many small impulses taken off b
revolving armature of the dynam
same direction along the circuit.
131 to 137. In Fig. 131, N and
ether between them is represen

ber of small impulses or waves following each other in quick succession.

A telephone in the circuit will sound at each fluctuation, and thus disclose their number.

79. Antecedent causes of the manifestations called electric and magnetic.—Experiment shows that some of the elementary substances that have strong affinity for each other at ordinary temperatures, gradually lose it when the temperature is lowered, and that at the extreme degrees of cold that can now be artificially produced, these elements become practically inert toward each other: if this inference be carried to the limit of absolute zero, where the elements have no heat whatever, no chemical combination could then take place. On this basis, heat is essential to chemical action. Now, heat and motion are mutually convertible, and so completely, that the exact equivalent of one in terms of the other is well known—so much mechanical work will produce a definite change of temperature, and the converse. Chemical action gives rise to electricity, and this produces heat or light; electricity excites the magnetic condition in a steel bar, and the *movement* of this bar generates a current in a wire, which in turn decomposes water—a chemical reaction, involving the existence of heat—that is, motion, and so, in whatever order the several phenomena be taken, they constitute a cycle returning into themselves, with motion for a beginning and motion for an end.

It will now be opportune to describe how it is that *antecedent* motion of different kinds produces electricity; that, in fact, the ordinary mechanical movements with which every one is familiar, as well as the wholly veiled ones of heat, light, and chemistry, are transformed into another motion that is electric and magnetic in its effects.

All matter is reducible to about seventy different kinds, and the atoms of these are variously in motion—translatory, rotary, oscillatory, and vibratory. These atomic motions are

tators C and C' are appli[illegible] solid state of matter,
impulses in the same di[illegible] greatest freedom in the
[illegible] nothing need be said;

[illegible] an example of oscilla-
[illegible] whole without necessarily

[illegible] a change of form of
[illegible]-fork whose prongs
Fig. [illegible] right and left. Such
is the current from [illegible] to ring and expends its
its fluctuations betw[illegible] reach the ear: sus-
noticeable, as Fig. [illegible] near the bell while utter-
[illegible] will be violently thrust
[illegible] parts of the body; in
[illegible] against the metal, and

[illegible] opposite vibrations re-
[illegible] plate may also illustrate
Fig. [illegible] with fine dry sand and
on the armature, [illegible] its edge, it will be
fering 90° in pha[illegible] off the loops and
commuted in Fig[illegible] of fantastic figures

[illegible] of the nature of the bell,
[illegible] molecules of matter
[illegible] wave, each bearing
Fig. 13[illegible] of one kind of matter
[illegible] elasticity, so necessarily
Here the h[illegible] waves: just as tuning-
the hills of the[illegible] in material—silver,
tuations in the[illegible] different rates of
More coils [illegible] as hydrogen, carbon,
six coils, the [illegible] emits not only a
cent of the wh[illegible] of its harmonics, so an
continuous c[illegible] vibration may have vari-

ations of it superposed—all sending out waves into the ether. More than this, the eternal jar and clash of atoms among themselves are so many spurs to their elasticity, changing the vibratory amplitude and hence also the resulting waves.

Such is the condition of matter on the Earth—ever emitting ether-waves of one length or another; but as many terrestrial substances have been shown by Spectrum Analysis to exist in the Sun, it is from that source that ether-waves of every kind—thermal, luminous, actinic, and electromagnetic—come in the greatest abundance.

A few specific cases of the production of electricity will now be described.

Any two substances whatever, brought into contact, will be endowed with opposite electrical conditions capable of setting up a current whose strength depends on the nature of the substances as well as on their difference of temperatures. This is illustrated in Fig. 138, where a bar of antimony, *mn*, bent

FIG. 138.

at both ends, is laid upon one of bismuth, *op*; a magnetic needle is pivoted in the space between them; both contact-ends being of the same temperature, no current will be excited, and the needle will rest in the magnetic meridian; but if heat be applied at one end, a current arises which deflects the needle. If, instead of heating the juncture, it be cooled by cotton moistened with ether, the current will be in the

restricted to very narrow limits in the solid ... opposite
less so in the liquid, and enjoy their greatest ... at the
gaseous. Of translation and rotation nothin... current
the name defines each. ... that they

A pendulum swinging to and fro is an ex...
tory motion—the body moves as a whole w... being
changing its form. ... in weight

A true vibratory movement implies a ... their
the body. Such is the motion of a tuning- ... only in-
—straight when at rest—curve to the ri... effort is
also is that of a bell that has ceased to ... above the
energy in those deep muffled tones that ... be reduced
pend a cork by a string and bring it nea... electrical effects
ing its expiring notes, and in places it w...
off—these are the loops, the moving ... and motion:
other places the cork will remain quiet ... both factors
these are the nodes where conflict of ... antimony and
sults in immobility. A square metal ... having been in-
the vibratory motion: if evenly sprea... that is varied.
a violin-bow be quickly drawn ac... change in the
thrown into vibration—the sand ... that had been
gathers along the nodes forming ... motion of heat
that vary with the rate of vibratio... Heat is due
... and periodic

It is vibratory motion somew... vibratory motion
plate, or fork that agitates the a... permeating the
and sends out into the ether, w... little waves is
the impress of its origin; for, a...
differ from another in weight...
do their vibrations and the re... consists of a cir-
forks alike in size and form, b... a grindstone)
steel, and aluminum, for ex... against it: here
vibration, so do the element... glass and leather;
and platinum: and also, as ... the hand or ma-
fundamental note, but also ... the gla-
atom besides its single cha...

..: particles into contact; it pro-
..ment in the molecules and from
..nd secondarily electricity as in the
..nd antimony just described. And
..otion was the variable factor—first
..nd *vibratory* in the molecule as heat,
..ether of the conductors as electricity,
..dentical with that from any other

..ne electricity has its origin in the visi-
..ss disc—*a mechanical motion;* in the
.. antimony, its source is the hidden
.. the atoms—*heat;* and in the voltaic

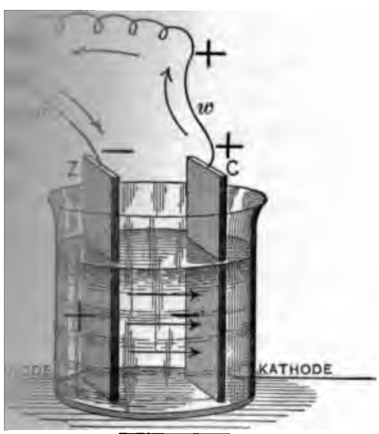

FIG. 139.

.. wholly veiled process of molecular forma-
..*eaction.* This cell, Fig. 139 and 140, con-
..milar metals immersed in acidulated water;
..be zinc and copper.

..mbination is the result of strong affinity be-
..oms, and covers a range of widely differing
..xydizes slowly in the air and the action is

... the senses; quicklime and water rush ... and we hear the sizzle and feel the

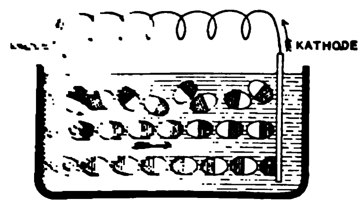

FIG. 140.

... detonation of gunpowder is so violent ... the eye and shock to the nerves—yet all ... reactions. Heat or light results from ... and light are due to motion—waves in

... substances present in the voltaic cell, ... strong attraction for each other: raised ... zinc will burn in oxygen as coal does ... as that does; but brought quietly ... in the voltaic cell, the zinc merely ... evolved energy becomes known only ... current when an exterior circuit ... the cell itself when no outer wire

... violent burning of zinc in oxygen we ... the slow combination of zinc and ... have heat—or electricity: heat is ... can it be doubted that the ... chemical reaction—electricity ... provision of a wire ... wave-motion in the ether ... we have the insepar-

... other with violence ... from the shock, and

these vibrations will excite undulations in the fluid: do not the shock of atoms in chemical embrace, since they too are elastic, set up equally in the surrounding ether those waves that produce heat or light or electricity according to circumstances?

The electric current in the wire will perform a variety of things which are in fact our only means of knowing its existence: if led into a motor it will run a street-car; passing between carbon points, it affords the luminous arc-light; it heats a platinum wire to redness; decomposes water into its elementary atoms; causes a vacuum-tube to glow with auroral beams; darts as a lightning flash several feet by means of the induction-coil; magnetizes a steel rod into a compass-needle, and if this be pivoted as in a galvanometer, the electric flow around it will deflect the needle, thus forming an exact means of measuring the strength of the current itself.

80. Mathematical treatment of physical phenomena and its predictions. — Light, like heat, electricity, magnetism, and other natural phenomena, has been treated mathematically, and analysis has followed the undulatory theory into the most intricate and hidden recesses that ether-waves penetrate. The form of these waves and the modifications they suffer in highly complex crystalline structures have been examined; and a reasonable explanation given not only of the simple facts of daily observation, but also of the entangled phenomena that lie deep down in the very groundwork of nature where only the most arduous delve.

In pursuing the mathematical vein of the theory, some physical aspects have been discovered that had never been seen, but which, when put to the test of experiment, were readily verified; this gives great stability to the theory, for to predict phenomena upon its principles, is to pay the highest tribute to its accuracy. The most notable instance of this kind is that of double-refracting crystals—a prediction that at

certain points the ray was divided, not into *two* but into *many* parts, forming a luminous cone instead of two images. Upon cutting a crystal of arragonite in the manner required by theory, the cone of light appeared as stated by the mathematician.

The facts of Diffraction afford another solid bulwark of the undulatory theory: not only are all such phenomena satisfactorily explained by it, but their variety of figure—dark and luminous, form and location—have been exactly calculated and subsequently verified by experiment.

When a little disc is placed in a pencil of light entering a darkened room, the natural inference is that it will cast a shadow on a screen at any distance: but mathematical formulæ showed that at certain distances of the disc from the screen the spot would not be black, but *bright*, and upon placing the disc at the required distance, the spot *was* found to be bright.

With faith in the Undulatory Theory of Light, one treads with greater confidence the maze of thermal, chemical, electrical, and magnetic phenomena, for they are all linked together—undulations of the same medium upon which the particular undulations called *luminous* have literally let in the light.

CHAPTER VI.

A GENERAL VIEW OF ELECTRICAL AND MAGNETICAL PHENOMENA.

Section One: Magnetism Universal in the Solid, Liquid, and Gaseous States of Matter.

81. Electricity is treated jointly with magnetism, because both generally appear together; wherever the former is *in motion*, the latter is also present, and therefore it becomes proper to treat them equally as disturbers of the peace of the Compass.

Just as all bodies possess heat to some extent, so they have the electromagnetic condition in different degrees: warm and cool streams flow through the general mass of air and water, because of difference of temperature and pressure; and electromagnetic currents permeate the Earth and air for a like reason—high and low potential.

Although it is only in a few metals that magnetism develops such strength as to be a dangerous menace to the Compass, still it will conduce to a better view of it to describe briefly the experimental means by which its universal prevalence has been established. Fig. 141 represents a powerful electromagnet with a glass cover above its poles to protect the little bar *b*, suspended by a silken fibre, from disturbing currents of air. The direction *AB* from pole to pole is called "*axial*," and a line at right angles to this between the poles is called "*equatorial*."

When the magnet is *in*active, the little bar *b*, no matter

of what substance made, will lie in any direction indifferently; but once it is alive with current, little bars of different substances will take one of the two directions—axial or equatorial: there is no indecision about their movement; iron will as quickly turn axially as bismuth equatorially, and if either be drawn out of its line of preference, it will quickly swing back upon release; and iron and bismuth, like the leaders of opposing clans, stand at the head of long lines of different kinds of substances that follow the direction of each. Matter organic and inorganic; mineral, vegetable, and ani-

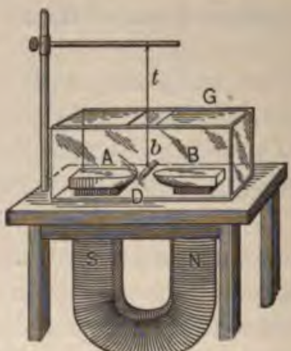

FIG. 141.

mal; as solids in bars, and as liquids and gases enclosed in thin glass tubes—all have been tested and marshalled under the heading axial or equatorial.

When a wrought-iron bar is suspended between the poles of a horseshoe magnet, it becomes temporarily a magnet too; poles of opposite name are *induced* in the nearest ends of the bar, and there is attraction between bar and magnet, and hence the former takes the axial direction, Fig. 142. On the other hand, if the small bar had been a steel magnet of nearly equal strength to the horseshoe magnet, it would be repelled and approach the equatorial position, Fig. 143: by inference, then, substances susceptible of magnetic induction

that take up the equatorial direction, have poles of same name *induced* in their near ends by the electromagnet of Fig. 141, and are repelled; and such is bismuth and its class. This view is supported by other experiments: place a sheet of paper on the poles of the electromagnet, and sprinkle fine bismuth powder on it; the particles will group themselves

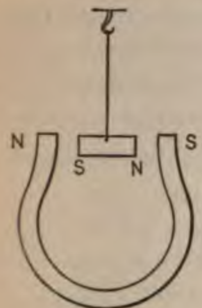

FIG. 142.

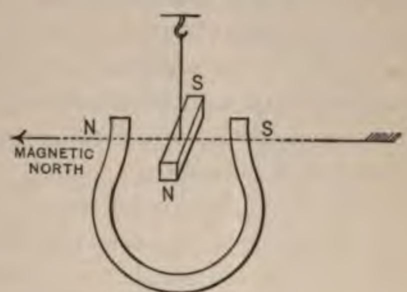

FIG. 143.

into the outline of the poles, leaving the space between clear; brush this off, and sprinkle a mixture of bismuth and a powder of some axial substance, as sesquichloride of chrome; the two powders separate, the dark bismuth, as before, showing

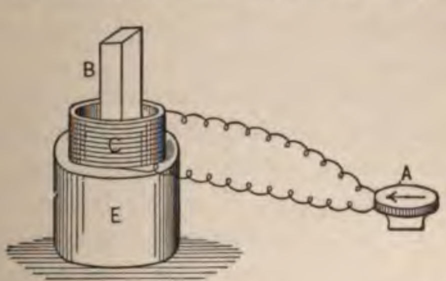

FIG. 144.

its equatorial character, while the violet grains of the other take the axial direction. Again: in Fig. 144, let E be an electromagnet with a coil of wire, C, on its upper pole, the ends of the coil leading to a delicate galvanometer A.

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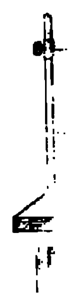

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zinc, copper, ivory, sulphur, water, olive-oil, hydrogen, and a host of other substances are diamagnetic.

There are various methods of determining in specific measure the magnetic or diamagnetic susceptibility of a substance, and the principle of one, as well as some of the results obtained by it, may be stated as follows: any substance introduced into a *non*-uniform magnetic field, experiences a mechanical force that urges it toward a stronger or weaker region of the field, according as the substance is para- or diamagnetic; and this force becomes known by measuring the strength of the field at various points; the avidity with which the substance moves, depends also upon its susceptibility to magnetism or diamagnetism. By using similar slabs of different materials in the strong field of an electromagnet, the susceptibility of each was determined. In fields of different strength, from one of 1620 lines per square centimetre to one of 10,450 lines, as well as through fields of intermediate strength, 3680; 8210; 8800; that is, different fields of these mean values, not these values for different parts of the same field, the susceptibility of bismuth (the most diamagnetic substance) was constant at — 12.4, the minus sign denoting diamagnetism. Other substances under same conditions showed magnetic or diamagnetic susceptibility as follows: marble, — 0.94; antimony, — 0.71; glass, + 0.58; cedar wood, — 0.16; oak, — 0.36; tin, + 0.35; ebonite, + 1.08; and alu-
— 0.16; oak, 0.36; tin, + 0.35; ebonite, + 1.08; and alumi-

The line of greatest density of a body will take the axial or equatorial direction according to the natural magnetic character of the body. Thus, a *cube* of bismuth will rest indifferently in any direction between the poles of an electromagnet; but if compressed by forces on two opposite vertical faces, the line joining these faces will indicate the most dense direction of the body, and the cube will turn until this line becomes equatorial. Again: if a paste of powdered carbonate of iron and mucilage be made and compressed into a

thin disc, this will hang with its plane equatorially, Fig. 145, and its line of greatest density, therefore, axially; if a similar disc of bismuth be prepared, it will hang with its plane axially, Fig. 146, and its line of greatest density, therefore, equatorially; if either disc be hung horizontally, Fig. 147, it will

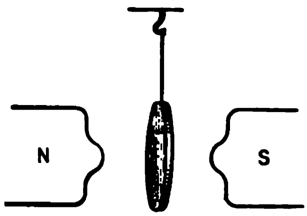

FIG. 145.

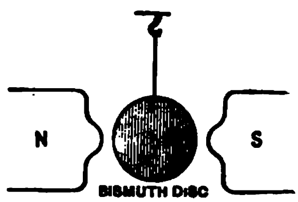

FIG. 146.

rest indifferently in any direction, because the line of greatest density is vertical and therefore at right angles to both the axial and equatorial directions.

All of which shows that the density of a body has much to do with its apparent magnetic condition.

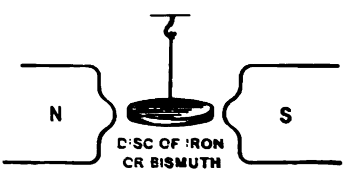

FIG. 147.

Temperature also affects magnetism: at a bright red heat, iron ceases to be magnetic, and at other temperatures cobalt and nickel become devoid of it; and diamagnetic substances are similarly affected, though each in different degree. The varied states of matter—gaseous as well as solid and liquid—follow the same rule; in fact, the law seems universal. Sulphur and mercury do not at the temperature tried, but this is no guarantee that they will prove exceptional at higher temperatures.

Later, a theory of magnetism will be stated that has received much favor: briefly, it consists in attributing magnetic effects to currents of electricity that circulate forever in the atoms of matter and are confined to the limits of the atoms—that the non-magnetic state is due to the axes of the atomic circuits being turned heterogeneously, so that the currents neutralize each other, as when two wires, the direct and return, are led side by side to destroy each other's effect—and that the magnetic condition becomes manifest when the atomic circuits are turned all one way.

Consider the bearing of density and temperature on this theory. No substance, however dense, is a *solid* mass of matter; but there are pores, interstices, void spaces, between atom and atom: the size of the atom is fixed, that of the space variable; compression reduces the space, heat enlarges it. Compression concentrates the effects of the atomic currents, just like a *pointed* conductor from which a spark leaps; whereas heat separates the atoms more, and spreads the electric condition over a large area, thereby lessening the potential: and thus the observed effects of varying density and temperature agree with theory.

82. The myriad sources of electricity and magnetism.—Any two substances brought into contact, or two parts of the same substance at different temperatures, give rise to a difference of potential between them, that is, to an electric current with its magnetic whirl; this current varies greatly with the substances used and also with the degree of heat applied to their point of juncture. It is the principle of the thermopile—a kind of electromagnetic thermometer. The principle may be traced in the static machine, where the *friction* of two dissimilar materials—glass and leather—brings particles of both into intimate contact, and heats them and excites electricity in abundance. Apart from this artificial machine, however, there are throughout Nature multitudinous instances of the friction of dissimilar substances that

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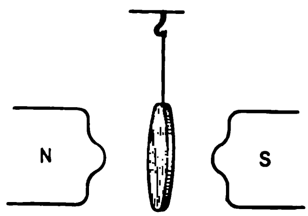

FIG. 145.

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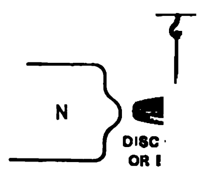

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many degrees of affinity between the atoms 'emical elements; and it is the tendency to ... degree of this attraction that impels atoms dislodge others and form new compounds: voluntary abandonment, atoms may be forci- nd both means of separation, or " dissocia- mical actions, which always disturb the elec- um of the rent bodies.

amount of heat will melt ice, still more will ..ter into steam, and more yet will disrupt this gen and hydrogen: the liquefaction and va- mechanical—the dissociation of the vapor, a n. It is effected through the agency of heat, view taken of this—the imparting to the atoms vibration or quivering as to swing them clear 's attraction.

.. is another, and the most efficient, agent for sociation of atoms. The process is termed Only certain liquids are amenable to this ; matter in the solid state, not at all. One in- decomposition of water—will be described, as it .. light on the production of electricity by chem-

148, *BB*, are two galvanic cells from which wires, to strips of platinum, *a* and *k*, called electrodes; .et into a vessel partly filled with acidulated water; s (closed at one end) are filled with water and in- er the electrodes. The platinum is not attacked by hat no chemical action takes place between the elec-

trodes and the liquid. The current from the cells enters by the anode, *a*, passes through the water—polarizing and decomposing it—and leaves by the kathode *k*. During its progress the water in the tubes will fall—forced down by the gases resulting from decomposition, which gather, the hydrogen about the kathode and the oxygen about the anode, and rise through the water in the tubes. The volumes of the gases are exactly those known to constitute water, and that they are really these gases, may be proved by puncturing the tops of the tubes, when the hydrogen will burn and the oxygen will cause a dying ember to burst into flame.

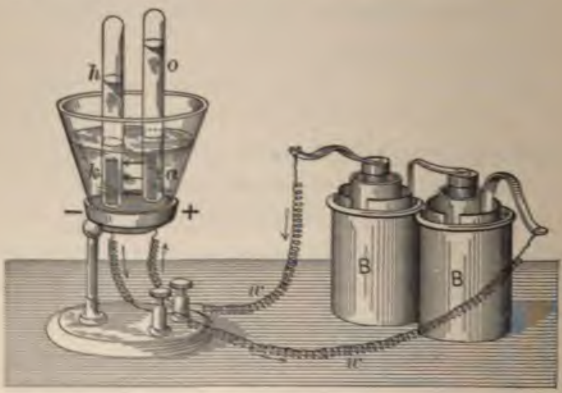

FIG. 148.

But the point especially to be observed in this process is, that each electrode is the rallying center for one kind of element, distinct from the other.

If the liquid had been chloride of tin, chlorine gas would collect about the anode, and metallic tin be deposited on the kathode. The principle is general, whatever the substance analyzed; and of all the chemical elements, about one-third will follow the example of oxygen, chlorine, sulphur, and bromine in seeking the anode, while the remaining two-thirds, like hydrogen, tin, copper, potassium, and the metals

generally, will proceed to the kathode. This points distinctly to two classes of opposite condition into which the atoms of matter naturally divide themselves: they proceed to the opposite poles of a battery; their voluntary union or attraction gives rise to a current of electricity (as will be presently shown), and this in turn will act as a forcible agent of disruption.

The two categories of atoms behave toward each other like oppositely charged conductors: bring these close enough, and they will rush into contact with a visible display of electrical disturbance—a spark: essentially a current.

This duality of electrical condition of all matter coupled with its duality of magnetic condition described in Art. 81, strongly point to polarity of this nature being the motive power that, as "chemical affinity," makes atoms cling to each other with varied tenacity, just as two magnets of different size and strength will; or, briefly, that chemical affinity is but electromagnetic attraction between atoms.

A dynamo excites a current of electricity, and this will run a motor, which is but the converse of the dynamo; motion goes into the dynamo and current comes out—current goes into the motor and motion comes out: similarly, the rending of atoms is the converse of their combination—electricity will effect the former, and it results from the latter. This will now be described.

Let Fig. 149 be a vessel containing a mixture of water and sulphuric acid into which a plate of copper and one of zinc are immersed: if either plate alone be connected by wire with an electrometer, it will appear electrified; if both plates are brought into contact, as in Fig. 150, the zinc wastes away, the acid grows weak, bubbles of gas rise from the surface of the copper, and if, now, the plates be quickly separated, a little spark will flash where they touched. An electrical disturbance has taken place while the plates were together: it is defined as a current—circulating in the direc-

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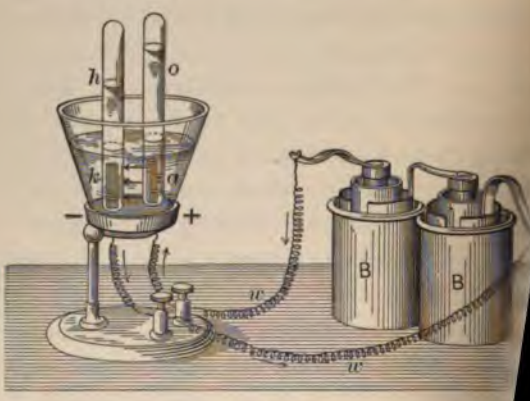

Fig. 148.

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the chemical action of one is so much more vigorous than that of the other that its current overshadows the weaker, and this is tacitly ignored. The stronger current in the present case is from the zinc, and the portion of this metal *in the liquid* is called the positive element, because the current starts from it; the part of the copper *in the liquid* is called the negative element, because the current comes to it (its own weak offspring being dropped from view): but *in air*, as the course of the current is *from* copper *to* zinc, these terms are reversed, and copper becomes the positive pole, and zinc the negative pole.

What is this current of electricity? Nothing *material*, either visible or invisible—as a current of water or of air—flows along the wire; and the energy existent there is known only by its effects—thermal, chemical, magnetical, physiological, and mechanical; for it will melt a filament of metal, decompose a liquid, direct a compass-needle, give a violent shock to a living body, or, if strong enough, propel a street-car along its track. Consider how this powerful energy arises: zinc and oxygen have strong affinity for each other; the latter exists in the liquid combined with hydrogen, and as a compound molecule moves about indifferently; but once the zinc is introduced into their midst, all the molecules face about in parallel lines and present their oxygen sides to the attractive electrode while the hydrogen faces the copper.

This is called polarization of the liquid. The acid loosens the tie between the atoms, the oxygen parts company with its mate, unites with the zinc forming oxide of zinc, and this in turn combines with the sulphuric acid, forming sulphate of zinc, while the hydrogen proceeds to the other electrode.

The usual explanation of the resulting current is, that each atom had a definite quantity of electricity—one, of the positive; the other, of the negative, kind—and that both delivered up their respective charges to the electrode of their choice. But *what* did they deliver up—a material burden?

Surely not. Motion? This well can be. If the current is denied passage by omitting the exterior circuit, the cell itself will become heated, and what is this but increased motion of the molecules.

Provide a circuit, and will not this increased motion take another form—still motion—and traverse it as an electric current?

A vibrating bell delivers up its motion to the surrounding medium and we have waves of air: why not the violent quivering of atoms consequent upon rupture, or their clash of combination, deliver up the increased motion to the ether in which they are immersed, and this take it up as an alternately stressed and lax condition, which is called a current of electricity? And it will be just as reasonable to conceive the different atoms of matter susceptible of definite motion of a certain kind, as to imagine them possessed of a specific charge of electricity, whether by this is meant a material liquid, a spirit, an effluvium, or something else equally vague.

Separately, the zinc, sulphur, and oxygen had more inherent energy than when combined as sulphate of zinc: so, too, the coal and air, before they met in the furnace, had more energy than the carbonic acid resulting from their combination; how account for the deficit? Energy has for factors, matter and motion: the former did not vary—the same quantity of matter was present in the changed state as before combination; it must, then, have been the motion that fell off as a factor of the compound and became manifest as a current of electricity in the chemical cell and as greater heat in the household furnace.

But, whatever is delivered up by the atoms—motion, or the vague electricity—its amount is always the same: the electrochemical equivalent of atoms is a well-defined quantity. The stronger the current, or the longer it runs in the electrolytic cell, the greater the number of molecules it will

separate; and conversely, the galvanic battery will yield current of a power and volume in strict conformity to the chemical reaction that takes place. The *same current* passing for the same time through several electrolytic cells holding the following metals in solution, will deposit 66 grammes of gold, 108 grammes of silver, 28 of iron, 28 of nickel, or 32 of zinc for every gramme of hydrogen liberated; and conversely, if these weights of the several metals be free and susceptible of combination with other elements, they will produce by such chemical action the same current for the same time that dissolved them from their bonds.

84. The Sun probably a source of electromagnetic energy.—According to the nebular theory, the various bodies of the solar system once spread out as a vaporous mass to the utmost confines of this system, and each body is due to a center of gravitation, which attracted to itself, during millions of years, the surrounding matter, until to-day we have the spherical forms of Sun, Earth, and planets. Even yet, fragmentary matter is adrift in interplanetary space, as shooting stars and other meteorites prove.

The contraction of the Sun—the gravitation of its mass into more dense volume—which is still going on, is considered the most probable source of its heat; for the grinding together of its constituents in this process will evolve great heat.

The Sun is shrinking, but so slowly that the amount, according to calculation, necessary to replace its radiation, would require nearly ten thousand years to be observed by delicate instruments.

Equal volumes of sulphuric acid and water—if mixed—will combine with avidity and give out great heat, the resulting volume being much less than the sum of the separate parts: shrinkage has taken place in the intimate chemical union of the liquids.

It has already been shown that the contact of different

substances produces electricity; that chemical action causes it; and that mechanical crushing, grinding, and compression of matter give rise to it: now, in the Sun there is a large variety of substances—iron, nickel, copper, zinc, sodium, carbon, hydrogen, and many more; the nucleus may be a viscous mass, but if so, it is the kernel of a molten shell that, in turn, is enveloped by a photosphere of glowing gas; in the Sun, therefore, all the conditions for producing the electromagnetic state, exist—variety of matter, great heat, chemical action, and the grinding and crushing of shrinkage: would it not, hence, be expected that what results from these conditions on the Earth should also take place on the Sun?

Section Three: The Electricity of the Air.

85. That the Air is a vast reservoir of electricity is abundantly shown by its periodic rise to a climax of tension and outburst in the thunderstorm. It has been examined by various means: long-pointed wires extending above the Earth; arrows shot upward; kites flown high in air; and balloon ascensions. Gilt thread connected these devices with an electroscope on the Earth, and thus the potential of the electrification was indicated as the arrow, kite, or balloon moved into upper regions.

Observations have been made in divers countries, at every hour of the day, in all conditions of weather, and at heights up to 23,000 feet; yet, beyond a few facts, little has been learned definitely.

In fine weather, the air, relatively to the Earth, is positively electrified, and the potential increases with the elevation; but in storms, with varying winds, cloudiness, rain, and other unsettled conditions, it is either positive or negative, and sometimes rapidly changes from one to the other. The condition may be likened to that of a Leyden jar—the

Earth negatively charged, the clouds positively, and the neutral space between, a dielectric: when the vapory mass becomes overburdened, the charge surges from Heaven to Earth in lightning flashes. Outside of these violent commotions, there is a regular ebb and flow of electrification, just as of tides in a harbor, or the atmosphere within the Tropics. The electrical fluctuation is as follows: a minimum about 4 a.m.; a maximum about 9 a.m.; a second minimum about 3 p.m.; and a second maximum about 10 p.m.; but each of these is a mean between considerable extremes, and they also vary with locality and season.

There is everywhere a decided difference between the electric potential of Winter and Summer: it rises from November until January—when it is greatest—then falls until March, and runs along at a low level during Summer, the average for the two seasons often differing as much as ten to one. The seasons in the Southern hemisphere cover months the opposite of those in the Northern, and as the electrical condition corresponds to the *season*, and not to the month, this indicates a connection between it and the movement of the Sun.

Various explanations have been offered (and combatted) for the electricity of the air: one constituent of the air itself is magnetic; processes are forever going on that yield electricity from both land and sea—evaporation and vegetation; and the Sun is considered a direct source. In support of this latter view is the hypothesis that the Sun sends out into the ether, waves of every length; those that produce heat, light, and chemical change we experience directly—but may there not be other waves which are transformed in the rarer strata of the atmosphere and become known to us by their electromagnetic effects? This would constitute the Sun the great central source of all these various forms of energy.

Oxygen is the most strongly magnetic of all gases; a cubic yard of it, compressed, would exert an effect upon a

magnetic needle equal to five grains of iron—that is, it lessens to this degree the Earth's directive force upon the compass, in the same way that a conning tower does: now this gas, in its free state, forms one-fifth the volume of the atmosphere; the air is forever in motion—often violently so—and the mere movement of these myriad magnetic motes should excite an electrified condition.

The solar rays decompose the carbonic acid of the air, setting free more magnetic oxygen and converting the carbon into leaf, wood, and bark; in due time these decay and carbonic acid is formed anew: quietly, but on a grand scale, it is the process of the galvanic cell—vegetation contributing to the electrification of the surrounding medium.

The hydro-electric machine is a means of producing electricity by evaporation: hot *wet* steam, by its friction against the inner surface of a pipe, becomes so charged with electricity that, upon issuance, it delivers up to a suitably prepared conductor such quantity that sparks several feet long may be drawn from it. If *distilled* water be dropped upon a red-hot platinum vessel connected with an electroscope, its mere evaporation will not give rise to electricity; neither will acids pure and concentrated: but solutions of acid and water will, and the *salt water of the sea,* which has been particularly examined, affords electricity in notable quantity when thus evaporated. If an insulated copper plate, spread with earth moistened with salt water, be exposed to the Sun's rays, electricity from evaporation will be indicated by an electroscope in connection with the plate; and the amount will be increased by agitating the air above the plate, for this will remove the air already charged and hasten the evaporation. Now evaporation is going on from every humid soil and salty sea, but most rapidly in Tropical climes: the general system of winds is upward from the Equator into higher regions, thence toward the Poles, steadily descending, and eventually toward tropical zones again as surface-currents; however

short a distance the warm vapor from equatorial seas may accompany the winds in their progress, it is constantly rubbing against new and cooler strata of air, composed—of what?—free atoms of oxygen (which is magnetic) and nitrogen—different kinds of matter in different conditions, essentially a state of affairs that in the hydro-electric machine supplied electricity in such abundance!

And exactly above the heated equatorial belt where these natural conditions of evaporation and friction exist for evolving electricity, *do* take place those vivid, violent, and deadly electrical commotions.

In Art. 82 many natural sources of electricity were named, and while no single one of them or of those stated in this article, may suffice to give the heavy charges that ofttimes burden our atmosphere, still all combined seem adequate to it; and they do exist, each contributing its share.

The electricity of the air is but an extension into space of the magnetic condition of the Earth, and therefore, for the purpose of this book, it is important that every fact contributory to its explanation should be made use of; it is not of the nature of mere information that may embellish a morning talk about the weather, but knowledge that enables us to understand the directing influence upon the compass: for this reason some very recent matter regarding the subject will be stated here. It appeared in *Engineering*, and was reprinted in *The Electrician*, from which it is quoted:

"It is curious to notice the extensive use made of kites in electrical exploration: they are not, however, as simple in build as that used by Franklin. The well-proportioned kites of the Hargrave pattern, while better able to cleave their way through the air and to remain poised in equilibrium for a long time, have only this in common with their historical prototype—that the fine cord which serves to fly them has a thin copper wire wound spirally round it.

"The end of this conductor is connected at the observ-

ing station with the needle of an electrometer, one pair of quadrants being kept at a constant high potential and the other at an equal low potential. This affords the best means of determining the electrical conditions of the higher regions of air. During the first few months of 1899 ten kite ascents were made at the Blue Hill Observatory, about ten miles from Boston. The average altitude attained was 7600 feet, the greatest being 12,300 feet. The most notable results obtained at the Blue Hill Observatory showed that showery or thunderstorm weather is not the only one which gives strong electrical indications: even with a clear and cloudless sky, the needle of the electrometer would move sometimes creepingly and at other times violently from its zero position.

"From the instrument-room of the Observatory it was easy to tell by watching the spot of light focussed on the scale [the visible means of showing the electrification], whether the kite was rising or falling, or whether it was stationary, the needle promptly responding to every change of altitude.

"On one occasion a kite was let out at 11 a.m. and kept up until 10 p.m.: toward sunset the spot of light became restless, and shortly afterward a storm was seen looming up from the west; while it continued, a perfect fusillade of sparks could be drawn from the wire, and as the darkness increased, a torrent of sparklets played between the air-gaps of the quadrants, the incessant sizzling threatening at times to burn the instrument out. . . .

"The following table shows the potentials recorded at two stations in Washington on a November day, the first being 500 feet above the ground and the second 45 feet. The apparatus used at both were the usual water dropping collector and its associated electrometer.

"Higher potential differences frequently occur in electric storms. Mr. McAdie relates that one May afternoon, while up in his Washington eyrie, 500 feet above the surrounding

thoroughfare, he noticed over the Virginia hills a patch of dark cloud, and thereby knew that a thunder-squall was at hand. 'At ten minutes to three (he writes) the clouds are overhead, and this is the last we shall see of the outside world until the storm is over, for it is necessary that the heavy marble door windows be swung to. All is dark in the [Washington] monument, save for the beam of reflected light travelling along the ground-glass scale.

Time.	First Station, Washington Monument	Second Station, U. S. Signal Office.	Difference.
1.30 P.M.	900 volts	216 volts	684 volts
1.32 "	888 "	246 "	642 "
1.34 "	900 "	216 "	684 "
1.36 "	862 "	246 "	616 "
1.38 "	875 "	240 "	635 "
1.40 "	825 "	222 "	603 "
Mean	875 volts	231 volts	644 volts

"'From the south window the nozzle of the water dropping collector protrudes through a small opening. The wind rises, and we notice the needle moving steadily toward the point marked 1000 volts positive. This means that the pull upon the air is steadily increasing. Suddenly the needle flies to the other side of the scale, and we know that the air, like a piece of overstretched rubber, has snapped under the strain. The pull is now negative; the needle dances about, and we hear outside the rumble of the distant thunder. Nearer comes the storm, judging from the rapid fluctuations of the needle: values of 3000 or 4000 volts are recorded.' [At the Eiffel Tower in Paris values as high as 10,000 volts have been registered; and the tension denoted by these numbers may be better appreciated when it is stated that 1500 volts are ordinarily used with the electric chair in New York for the execution of criminals.] 'Placing the eye close to the peephole through which the nozzle protrudes, the little stream of water is seen twisting and breaking into spray, but becomes

normal as soon as a flash occurs, only to begin to twist and disturb itself again.'

"Such, in brief, is the history of most of our thunder-storms, as it is also of snow-storms, and especially of hail-storms.

"During these last, the behavior of the spot of light is often of the wildest character, thereby denoting electrical disturbances of a high order. . . .

"In ascending through the atmosphere during normal conditions of potential, a rise of about 50 volts per foot will be experienced; but steeper gradients are not uncommon. To determine the limits of the electric field beyond the Earth, we must appeal to observations taken at the greatest possible heights. An analysis of the records of the Observatory situated in Salzburg at an altitude of ten thousand feet, as well as of observations taken in balloon ascents, tends to show that this normal field, like our atmosphere, is confined to comparatively small limits: while the atmosphere does not much exceed one hundred *miles*, the electric shell seems not to extend beyond ten or fifteen thousand *feet*. At this and greater altitudes there appears to be such little appreciable variation of potential that we may say the field is practically constant: this would mean that the Earth's lines of electric force end at about that elevation, and that we have there the location of the positive charge corresponding to the negative electrification of the ground.

"This layer and the surface of the Earth form the coatings of Nature's great condenser. Our buildings and monuments project some little distance up between them, and the heavier clouds of our skies sail about at varying heights through this heterogeneous dielectric.

"It is not enough, however, to recognize the fact of this electrical separation; we want further to know what may be the causes of so remarkable and permanent a phenomenon. . . Some of the causes have already been mentioned,

and two of them will now be dealt with a little more at length. That the rubbing of dust and sand particles against the air is a potent cause of electrification, is well borne out by observations made in the Sahara Desert, especially during the prevalence of the sirocco. M. Fèret, writing in *Cosmos*, Oct. 17, 1899, says: 'Il suffit alors d'une couverture brusquement déployée, d'un peigne vite passé dans les cheveux ou la barbe pour produire des étincelles. Les tentes se transforment en autant de bouteilles de Leyde, d'où l'on peut tirer au plus leger frôlement des étincelles de 15 et même 25 centimetres.' . . .

"By a very careful investigation, Prof. Lenard showed that when drops of water fall upon a water-surface, they give a negative charge to the air; and if allowed to fall upon a hard, wet slab of any material, the air-charge is considerably increased. He also satisfied himself that no charge was communicated to the air while the drops were actually falling, the seat of electrical disturbance being the agitated water at the foot of the fall or the rocks on which the drops impinged. He also found that the negative electrification of the air was modified by the presence of common salt dissolved in the water, as small a quantity as one per cent sufficing to change its sign. With five per cent the development of positive electrification was a maximum.

"These results appeared to have such an important bearing on electrical theory in general, and also on the origin of atmospheric electricity, that they were repeated by Lord Kelvin and Mr. McLean in the physical laboratory of the University of Glasgow. All Lenard's observations were confirmed but one, the exception being a very important one. These Glasgow experiments did not show, as Lenard inferred from his, the absence of all electrification while the drops were passing down through the air; for, when there was no obstruction to the artificial shower, evidences of a

... egree of negative electrification were always detected. ... significant and suggestive observation, because ... records almost always indicate strong nega... ... while rain is falling.

From these researches we conclude that every rain-drop ... on the ground, or on ponds, lakes, and rivers, as well ... every drop of fresh-water spray falling back on a fresh-water surface, sends a minute quantity of negative electricity ... whilst every drop of salt-water spray falling ... into the sea from breaking waves sends positive electricity into the atmosphere. As by far the greater part of the ... surface consists of saline waters, positive electricity ... greatly preponderate. It is not unlikely, then, that we ... the tossing and wind-driven surface of our oceans a ... power house ever at work in generating the normal positive electrification of our atmosphere."

Section Four: The Magnetism of the Earth.

... Aside from the fantastic olden theories, which it were ... to recount, the magnetic condition of the Earth has ... ascribed to magnets located within its bowels—to a ... one at its center; to two such inclined at an ... with each other; to a solid sphere revolving inside an ... both magnetic, and each with its foci and period ... different from the other. But all such were ... representations of observed facts, in the same ... electricity was explained by a fluid—the material ... the attributes, but the image was the figment, ... the reality. Existing physical conditions, however, ... reasonable explanation, and are more worthy ... attention.

... magnetism of the Earth and electricity of the Air are ... connected and mutually retroactive, so that the

statements of the preceding Article really form a part of this.

The magnetic influence is not like the rind of an orange, of definite thickness; but it penetrates the mass of the globe and spreads out into space: in the deepest mine the compass will point to its Pole, and at successive heights, up to twenty thousand feet, at which experiments have been carried in balloons, a horizontal needle made the same number of oscillations in a specified time as at the point of the Earth's surface from which it started. A very thin layer of this magnetic atmosphere—that immediately enclosing the globe as a shell does an egg—has been thoroughly examined during long years, and the result stands clearly forth that the Earth is a magnet, but roughly so—contorted and misshapen. The magnetic atmosphere is considered streaked with lines of force whose direction is indicated by delicately poised needles: these are necessarily confined to the Earth's surface; above and below exist the conditions that give them direction, as well as arise the fluctuations that divert them from their normal positions, for the lines quiver with many changing circumstances.

The Earth is full of all the different kinds of metals, heaped in masses, spread out in beds, pure, combined with each other, and variously agglomerated with other substances; throughout them all percolate acid liquids, as the multitude of mineral waters that spring to the surface, attest: here, then, is a network of galvanic cells of every form in perpetual activity, probably exciting currents of electricity that flow beneath the crust upon which our needles are pivoted.

Again: where acidulated waters do not run, different metals still exist, variously distributed in quantity and space from Equator to Pole; they touch and join in layers and veins; the Torrid Zone is forever heated, while the Poles are capped with eternal snow, thus making of the Earth a huge thermopile for exciting electric currents.

These are continually varying in strength and direction, for, being (presumably) dependent on the Sun, as this is vertical over different parts of the Earth at successive hours of the day and throughout the several months of the year, the heating of the globe is a progressive action; hence the electric currents due to it manifest their fluctuations in the daily, monthly, and yearly maxima and minima of magnetic phenomena: nothing is better established by observation than the coincident movement of the magnetic needle and the Sun.

Heat weakens the magnetic condition, and accordingly this has its least intensity in the heated zone, while the foci of magnetic strength and regions of severest cold are close together.

As coal, gold or copper is found only in certain places, so magnetic ore is more abundant in one hill or ridge than in another: one has but to cast his eye on the daily weather map to see how mountain ranges give twisted contours to the lines of equal temperature and pressure; similarly, masses of magnetic ore outline in warped and tortuous curves their characteristic features, as portrayed on any chart.

From all these sources—chemical and thermal effects upon the metals of the Earth as well as local magnetic deposits, coupled with the reflex action of aerial electricity—we have what seems a plausible explanation in part, at least, of the electromagnetic condition of the globe and its irregularity—its ill-shapen form of a magnet.

That terrestrial electric currents do exist is not a mere inference: they were first observed during great auroral displays by reason of their interference with telegraphy, when, occasionally they surpassed the strength of the regular working current: but now they are observed at all times in all places, well defined though usually weak, and wholly due to the Earth and not to any adventitious circumstance.

So much for what goes on beneath the surface—now in

the air above we find conditions that contribute to the same general result.

In Art. 85, it was shown how streams of vapor rising from tropical seas proceed toward each Pole and may excite currents of electricity in those directions; it is the parallel of the thermo-electric currents running in the same way through the Earth: both are due to the Sun heating the middle zone of the Earth; and their variable strength—manifested by the annual change in the magnetic elements—is due to the apparent motion of the Sun toward either Pole during the year. The apparent motion from east to west gives rise to currents in this direction, too; for as the Sun heats the segment of the Earth immediately beneath it, that to the westward is cooler, and on the thermo-electric principle, the currents flow from the warm to the cool joints of the metals: their variable strength—manifested by the diurnal change in the magnetic elements—is due to the alternate warmth and chill that recur with day and night.

Thus there are conditions that may give rise to currents from east to west in Earth and Air; there are also conditions that may give rise to them from Equator to Pole—also in Earth and Air; these sheets of electric flow would make of the Earth a huge solenoid with a pole in each hemisphere, *un*symmetrically located, as actually exists, because such poles result from the combination of the meridional currents with those flowing along parallels of latitude, and both systems can hardly be imagined exactly equal; there are magnetic ores variously heaped in different parts of the Earth; and there are cyclones that whirl immense volumes of magnetic oxygen from region to region of the atmosphere: the Sun comes along—one day is hot, another cool—and all these sources of the electromagnetic condition vary; they mutually react upon one another as would so many magnets dangling from strings, and it is the resultant of the whole that we observe in the movements of our little needles piv-

oted all over the thin crust of earth dividing the currents and commotions above from those beneath.

These thermo-electric and chemico-electric currents attributed to metallic deposits in the Earth as well as the currents ascribed to aqueous vapor rubbing against the air, are inferences drawn from the conditions of matter existent in both Earth and Air, and not at all demonstrated facts: indeed the sources of aerial electrification and terrestrial magnetism are enveloped in a dense haze through which every form that peers is seized upon and investigated to wrench from it anything like a rational theory. Such is the foregoing, and such also is a theory—the latest—that will be presently stated.

There is no reason why we should consider the range of waves coming from the Sun limited to those observed: indeed experience warrants quite the contrary. At first, light was considered simple—a pure white emanation; the prism revealed its compound nature, and the undulatory theory assigned to the varied refrangibility specific wave-lengths, so that wave-length and color became synonymous terms; but the range was restricted to those producing visible effects. Then the long dark waves below the red were discovered, which are peculiarly strong in thermal effects; and next photography disclosed the short and equally obscure waves above the violet, which are specifically chemical in their action. Now the cathode and X rays are becoming prominent—extremely short waves which in themselves (or by transformation) seem especially productive of electromagnetic effects.

From these through the ultra-violet, the luminous, and the thermal, the wave-length is a steadily increasing quantity; and who shall say that beyond each extreme there are not other octaves of waves without limit—longer and shorter—and producing other effects than those with which we are at present familiar?

"If we should contend for a transformation of what we call light waves into electrical and magnetic waves, we should be in line with the present tendency of scientific thought, which more than suspects that light and heat and electro-magnetic waves do not differ in any respect except in regard to length."

This is the statement of Prof. John Trowbridge of Harvard University, who has offered the latest explanation of the magnetism of the Earth, an outline of which will now be given in extracts from his writings:

"The X rays are now believed by the best authorities to be magnetic and electrical pulses or waves of extremely short length. In the spectrum of sunlight formed by sending a beam through a prism of quartz, the X-ray pulses or waves are to be found, according to this hypothesis, beyond the

FIG. 151.

violet color of this spectrum—far into the dark region invisible to the eye, and only brought into view at present by the aid of photography. In this invisible region reside many singular manifestations of energy closely analogous to those of the X rays. . . . For the artificial production of X rays, a bulb of thin glass, Fig. 151, exhausted of air, is used: *C* is a concave aluminum mirror and *A* a plane inclined sheet of platinum; *R* is a small chamber containing a certain chemical

which, being heated, gives off a small amount of vapor, that is taken up again on cooling—this controls the degree of vacuum. The conduits from the source of electricity are attached to the electrodes *P* and *N*—platinum wires soldered into the bulb. The source of electricity may be of various kinds, the principal being an induction-coil in connection with voltaic cells, or a number of Leyden jars charged by a storage-battery, the *dis*charge being one after another, so as to obtain a high electromotive force. . . . This method is a very flexible one—being capable of experimenting over a range of electrical pressure from twenty thousand volts to three million; the spark from the latter is over six feet in length.

"In the bulb, the discharge passes between the mirror *C* and plane *A*, and the X rays are thrown off from the latter: they are not reflected in the ordinary sense of the term, but the electric rays converge from the mirror *C* to a spot on the plane *A* which glows with a red heat, and the X rays emanate from the heated spot as if it were their source. . . .

"At one time I supposed that the rays were highly absorbed in passing through atmospheric air, and that it would be an improvement to interpose a vacuum-chamber between the body and the source of the X rays. . . . The vacuum-chamber consisted of a glass cylinder three feet long and about eight inches in diameter, closed at the ends by sheets of aluminum, which gives free passage to the rays. . . . This cylinder having been exhausted, was placed between the X-ray bulb and the arm: it was speedily seen that the absorption of the layer of air three feet thick [when the exhausted cylinder was *not* interposed] could not be detected either by photographs or the fluorescent screen. The glass cylinder was then filled with rarefied hydrogen, but no advantage was apparent.

"If the photographs of the human hand were taken, one through the rarefied cylinder and the other through an

equivalent thickness of air, no difference in clearness of definition could be perceived. The amount of absorption by a column of air three feet in length is less than ten per cent. This result shows the remarkable difference between the X rays and the cathode rays; for the latter are greatly absorbed by the atmosphere, being reduced in passing through six inches of air to one four-hundredth part of their value. The small amount of absorption of the X rays lifts them into the realm of very short wave-lengths of light, for their behavior in regard to the absorption by air is very analogous to that of ultra-violet rays.

"Although the vacuum-chamber through which I looked showed no absorption of X rays, still it disclosed a beautiful phenomenon. If the finger were brought near the glass walls of the cylinder, a stream of light apparently emanated from a point on the inside wall of the cylinder. The hand thus had ghostly streamers giving an image of it, although the hand itself was invisible.

"These banners of light could be diverted in any direction by the hand or by any conducting body brought near, and gave a vivid conception of how the streaming of the aurora can be brought about by the flitting of conducting clouds or the drifting of moisture-leaden strata of air below the rarefied space in which the beams of the Northern Light dart back and forth. Both in the case of the vacuum-tube and the aurora these streamers are produced by electrical discharges through rarefied air. The experiments show that outside the vacuum or Crooke's tube there is a strong electrical attraction and repulsion, which is only revealed in darkness and in a cold, lifeless, airless space, such as exists between us and the Sun. Can we not extend our thoughts from the contemplation of the laboratory experiment to that of the immensely greater play of electrical forces between the Earth and the Sun across the immense vacant space ninety millions of miles in distance? . . .

"When the Crooke's tube is excited, we are conscious of a mysterious activity within it, for its glass walls glow with a phosphorescent light, and if crystals, like the diamond or ruby, are placed in the tube, this phosphorescent light is vivid. Outside the tube, in free air, these luminescent effects are also present. The air is under an electrical strain, which is shown by the auroral streamers when this air is rarefied, and an electrical charge can not be maintained on a pith-ball—it is dissipated in some strange manner. Still stranger, an electrical current is greatly aided by the X rays in its endeavor to pass through air—they make the air temporarily a conductor.

"Furthermore, these rays separate the air into positively-laden and negatively-laden particles.

"The electrical discharge in the Crooke's tube is many sided in its manifestations. Its energy seems all-pervading in the room where it occurs. Before the discharge passes through the rarefied space in the tube, its energy manifests itself by a crackling spark—a miniature lightning discharge.

"This spark, five or six inches in length, can send out magnetic waves which extend far beyond the narrow limits of the room. They can be detected by the methods of wireless telegraphy fifty miles. When the same amount of energy is developed in a Crooke's tube, the magnetic waves hardly pass beyond the walls of the room, and the phenomenon of phosphorescence and fluorescence and the strange molecular effects outside the Crooke's tube spring into prominence. The crackling spark outside the tube is far-reaching in its effects, yet it shows no signs of the X rays, its light can not penetrate the human body, it excites only a feeble phosphorescence at a distance of even two or three feet, while the same energy excited in the Crooke's tube can cause luminescence at a distance of twenty feet. . . .

"When we consider these experiments [made by Prof. Trowbridge and which it were needless to recount], we see that the X rays act toward phosphorescent matter much as

the spark in air behaves toward the photographic plate. Now these results, taken in connection with the strong electrical effects in the neighborhood of an excited Crooke's tube, point to a certain connection between phosphorescence and electricity. Can it be that the strange light is excited by very short electrical waves sent out from the tube, which can not travel far, but are very active in producing molecular effects? This activity, indeed, may prevent their extending to great distances.

"Wireless telegraphy evidently depends upon one set of waves sent out by a spark, and X-ray photographs upon another set developed only in rarefied air. Phosphorescence can not be produced with ease by the spark in air. On the contrary, it is developed to a remarkable degree and at comparatively great distances by the discharge in rarefied air. It has been shown that electrical force can develop phosphorescent light in crystals: the sunlight can do the same: is sunlight an electrical phenomenon? That it is, constitutes the greatest hypothesis in physics of this century. . . .

"Besides the photographic, the phosphorescent, and the fluorescent effects, there are still more singular properties of the X rays. One of the most striking is that they open a path for a current of electricity. The electrical discharge, feeble in itself, not capable of lifting by means of a motor a pound weight a foot from the floor, is yet competent to open a path for a current which can set all the trolley-cars of a great city in motion. To exhibit this mysterious effect we bring the ends of the electrical current which we wish to excite near each other, but not touching, in a glass tube with thin walls, from which the air has been exhausted.

"When the X rays fall on the gap between the wires, the electrical current immediately jumps across the gap with a vivid light. We have here the mechanism of an electrical relay—the feeble energy of the electrical discharge [that] can call into play a giant energy. By what energy does it

accomplish this? Is it by compelling molecules to put themselves in line, so that the electrical current can bridge the gap? . . . Another far-reaching manifestation is this: the rays can separate the air or a gas into its constituent particles much as a strong electrical current separates water into oxygen and hydrogen.

"They can communicate electrical charges to these particles—positive and negative charges. The charged air-particles, when forced through partitions of spun glass, do not give up their electricity as they do when they are charged by an electrical machine. This curious manifestation leads me to suspect that the electricity and magnetism of the Earth may be caused by an X-ray effect on our atmosphere.

"The Sun and the Earth are separated like the terminals of a Crooke's tube—two conductors with a vacuum between.

"An electrical excitation from the Sun may cause an electrical discharge between it and the Earth: this discharge might consist of an X-ray effect which could separate the upper layers of the atmosphere into positive and negative charges. The velocity of the negatively charged particles is greater than that of the positively charged ones, and the revolution of the Earth may cause such a movement of these electrified particles that electrical currents may be generated which in circulation round the Earth could produce the observed magnetism together with the auroral lights. This, I am well aware, is an audacious theory—certainly a vast extension of the laboratory experiments described; but the electrical radiations developed in electrical discharges are as competent to produce powerful magnetic whirls as the heat radiations in our atmosphere to develop cyclones. In the lower regions of our atmosphere the air is an insulator, like glass to the passage of an electrical current: a layer a foot thick can prevent the circulation of the most powerful current now used to generate horse-power. When this air-space is rarefied to a certain degree, the current passes, especially

if the space is illuminated by X rays. When, therefore, we ascend to a height of ten or twenty miles, the rarefied air becomes an excellent conductor of high electromotive force.

"To my mind the conditions exist for developing an electrical state in the Earth's covering of air, which is competent to explain the electrical manifestations of the air, the auroral gleam, and the effect on the compass which directs it to the magnetic north. . . .

"The Sun, although it probably does not electrify our atmosphere as one charged pith-ball electrifies another, or produce the magnetism of the Earth as one magnet induces magnetism in a piece of iron or steel, is undoubtedly concerned in both the electrical state of our atmosphere and the magnetism of the Earth. . . .

"It has lately been discovered that X rays have the property of communicating an electric charge to conductors. If, therefore, X rays reach the Earth from the Sun, they are competent to give an electric charge to our atmosphere. The side, therefore, of the Earth turned toward the Sun would receive a charge in the upper good-conducting regions of the air. This charge would tend to dissipation; and there would be a flow of electricity toward the side of the Earth not turned to the Sun. The rotation of the Earth on its axis from west to east would bring forward at each revolution fresh regions of the upper air to receive the electrical charging from the Sun.

"There would be an accumulation of electricity on one side of the Earth and a diminution on the other. The conditions of equalization, or flow of electricity, might be determined by the rotation of the Earth. If this flow took place from east to west, and were sufficiently powerful, it would produce the magnetic poles.

"It has been found that air submitted to the action of the X rays continues for some time to manifest their influence. We should, therefore, expect a fall of electric pressure be-

tween the regions just entering into daylight and those in the full glare of the Sun.

"This condition would direct the resulting electric current from east to west. By means of this theory we have substituted for a tremendous action at a distance, namely, an electrified pith-ball effect, or an action of a great magnet, an action from point to point by means of waves from the Sun. . . . The North Pole of the Earth is just within the Arctic Circle, the South Pole is south of Tierra del Fuego: therefore, they are a great distance apart. If the Earth were composed of steel, and were magnetized permanently in the beginning, it would be impossible that two poles should occur eight thousand miles apart. There would be other poles, or what are called consequent poles, between the north pole of the Earth and the south pole. The two poles of the Earth must be due to what is termed a solenoidal action, that is, an action similar to that which a current of electricity exerts in circulating through a coil of wire. A north pole can be removed from a south pole by this arrangement as far as desired; while the longest permanent magnet that can be made is barely three feet in length. The distance, therefore, between the magnetic poles of the Earth is a strong argument in favor of the theory that they are produced by electrical currents circulating about the Earth. . . .

"The theory promulgated above supposes that such currents result from the conversion of the shortest waves of light into electricity, and that the flow is brought about by the rotation of the Earth. This theory demands a high state of electrification of the upper regions of the air, and great conductibility in these regions: thunder-storms are evidence of the former; and the increased conductibility of rarefied air, up to a certain limit, can be abundantly shown.

"One of the most striking methods I have employed to show this, consists in connecting a battery of ten thousand storage-cells to two terminals which are separated by a space

of six inches of air. When the air is exhausted from the space between these terminals to the degree of rarefaction which exists about six miles above the surface of the Earth, the current from the battery leaps across the space with the greatest ease. Indeed it is conducted by the rarefied medium almost as well as if this medium were a metal like copper."

When, more than twenty years ago, Prof. Crookes gave prominence to electrical discharges in vacuum-tubes, he considered the luminous effects due to particles of gas which became electrified by contact with the negative pole (or (cathode), and were then shot off in straight lines—the cathode rays. When these, Fig. 151, impinge on the platinum plate *A* (the anode or anti-cathode), a new kind of radiation seems to start from the point of impact—the Röntgen or X rays.

That the cathode rays are really due to streams of luminous electrified particles—whether individual atoms, single molecules, or aggregations of matter—is proven by placing a small aluminum wheel in their path; it will be driven from the cathode; on the other hand, when this wheel is drawn from the middle line of the tube toward either side, it will be moved from the anode, showing that there is a stream of positively charged particles from that pole: it is a complete circuit—*aller et retour*—with the negatively charged motes having much the higher velocity; they will bore minute holes in a block of quicklime in their course and raise it to beautiful, brilliant luminosity.

What are the Röntgen rays that arise from these cathode beams? The most generally accepted theory is that they are extremely short ether-waves, in all respects like those of light, only so much shorter than even the most ultra-violet waves, that they readily pass through the interstices of the ultimate particles of matter, and therefore can not be refracted or easily absorbed by any substance. Another explanation [from Prof. Swinton in *Nature*] is: Each cathode-ray atom

carries a negative charge, while the anti-cathode is positively charged, so that when the two come into contact an electrical discharge will take place: an electrical oscillation will thus take place in the atom just as in the brass balls of a Hertz oscillator, and transverse electromagnetic waves will be propagated through the ether in all available directions.

But they are otherwise variously accounted for, although the explanations given above seem the most reasonable: in fact, the unknown quantity has not yet been removed from the problem—they are still the X rays.

87. Local masses of magnetic ore and rocks.—The smallest experience with magnetic instruments over even a very restricted area will disclose the existence of ores in ledges, beds, and strata that produce abnormal deflections; this aside from the well-known effect of volcanic matter: a general examination of all such is not intended in this article—only the citation of a few typical cases, to give point to the statement that it is most probably immense masses or mountains of magnetic ore, irregularly distributed, that make of the Earth an *un*symmetrical magnet.

Near Zell in Germany there is a ridge whose whole eastern slope presents magnetic polarity of one kind, and western slope polarity of the other; it is composed of layers through which particles of iron are strewn that may be picked out by a magnet on pulverizing the ore: the ridge acts upon a compass thirty feet away.

In Enderby Island, Ross, during his Antarctic voyage, found two stations not a hundred feet apart where the dip differed 11°; the rocks had a peculiar ferruginous appearance, and on approaching pieces to a delicate compass, they turned it round and round as swiftly as the hand could move; they were powerfully magnetic, the poles depending on their direction with reference to the magnetic meridian.

Recently, near Pulkowa, Russia, the extreme values of the three magnetic elements at fifteen stations scattered over

an area of one square kilometre were: Variation, from + 58° to — 43°, or a total of 101°; Dip, from 79° to 48°, or a total change of 31°; and horizontal intensity from 0.166 to 0.589 C.G.S. units, or a change of 0.423 C.G.S. units.

In 1885, a British surveying vessel experienced a steady deflection of 30° off the N.W. coast of Australia, although the line of "no-variation" passes in the vicinity, and the extreme of 5° E. var. to 5° W. var. covers that section of coast. In 1890, in the same locality, another vessel found a deflection of 22°. The ship was immediatly anchored, and some hours of the following day spent in investigating the matter: on Bezut Id. itself, the absolute values of the Variation and Dip were normal, the dip being 50° S.; but at a position N. 79° E., distant 2.14 miles from Bezut Island, the Dip was observed on board to be 83° S. with a very small deflection of the compass. At 900 feet west of this the Dip was normal, and it decreased rapidly as the center was quitted in any direction. At about one hundred feet south of the center of disturbance the compass was deflected 55°. This was the maximum, but the compass was disturbed over an area of a square mile. The general depth of water in this area was nine fathoms, bottom, quartz sand. The observation of the magnetic elements at Cossack and the neighborhood showed little or no disturbance from local magnetic causes.

It is therefore evident that the disturbances were due to magnetic minerals at the bottom of the sea.

Capt. Rogers of the Steamship *Coronilla* states that in 1896, while on the east coast of Sweden, on approaching Hafringe Lighthouse, bearing N.N.W., distant six miles, the standard compass suddenly started swinging over an arc of sixteen points. On mentioning this to the Pilot, he told him of a 19-fathom patch on that bearing and distance which had been found to affect compasses in that way; and that both the bank and its effects are noted on Swedish charts.

The sea was smooth at the time of observing the compass start swinging.

As a fitting close to this Section, I will quote the following from a lecture by Prof. A. W. Rücker, F.R.S., delivered in 1897 in the Senate House, Cambridge, England.

"The Declination [Variation] is greater in Ireland than in England; but the increase is not uniform as we pass from one country to the other: in fact in some districts an abnormally large increase is followed by a decrease. These curious inequalities must be due to local disturbing forces, and the large number of observations which have been made in this country have enabled us to determine with more than usual accuracy the magnitude and direction which the magnetic forces would assume if they were undisturbed by any local cause; and from the difference between things as they then would be, and things as they actually are, we can calculate the magnitude and direction of the disturbing forces themselves. When these are represented on a map, it is found that there are large districts in which the horizontal disturbing forces act in the same direction; in one region the north pole of the needle will be deflected to the east, in another to the west, and as we pass from one of these districts to the other, we always find that at the boundary, the downward vertical force on the north pole of the needle reaches a maximum value. We are thus able to draw upon the map lines toward which the north pole of the needle is attracted. It is found that the lines can be traced without any possible doubt through distances amounting, in some instances, to a couple of hundred miles. The key to this curious fact is furnished by observations in the neighborhood of great masses of basalt or other magnetic rocks. If these were magnetized by the induction of the Earth's magnetic field, the upper portion of them would, in this hemisphere, attract the north pole of the needle; and it is found that where large masses of basalt exist, the north pole of the needle is, as a

matter of fact, attracted towards them from distances which may amount to fifty miles.

"The thickness of the sheets of basalt is in most cases too small to furnish a complete explanation of the observed facts, but it is quite possible that these surface layers of magnetic matter are merely indications of underground protuberances of similar rocks from which the surface sheets have been extruded. . . . From the neighborhood of Reading a magnetic ridge-line runs southward, entering the [English] Channel: M. Moureaux has discovered the continuation on the French coast near Dieppe and has traced it through the north of France to some fifty miles south of Paris.

"The energy which is now being displayed by magnetic surveyors in many countries will no doubt before long prove that the network of these magnetic ridge-lines is universal.

"At all events we may hope that amid the flux and change of magnetic forces, we may have found in these ridge-lines physical features of the country as permanent as the hills themselves. . . .

"Magnetic problems are still surrounded by doubt and difficulty—with questions which can only be answered by the combined work of many men, it may be of many generations. . . . It is true that on some of these matters we are gradually acquiring definite knowledge: but greater questions which lie behind these are still unanswered."

CHAPTER VII.

THE MAGNETIC ELEMENTS OF THE EARTH.

Section One: Terrestrial Magnetism Illustrated and Defined by Lines of Variation, Dip, and Intensity.

88. The ethereal atmosphere and its surgings.—The Earth has two distinct atmospheres—one of air, the other of ether: both occupy the same space; they commingle but do not interfere; they affect wholly distinct instruments, and yet each has movements not unlike the other, and due in part to the same cause.

Constant agitation, periodic and accidental, characterizes both; while time and place give a kind of local color to every fluctuation.

Over a very wide belt of equatorial regions there is a regular ebb and flow of the air—two daily maxima and minima, as indicated by the rise and fall of the barometer; and so over the same region there is a like movement of the ether as shown by the deflections of a magnetic needle east and west of its mean position—two daily maxima and minima.

Beyond this belt, in both air and ether, there are disturbances of an irregular nature, increasing in amount as we approach either Pole.

Cyclones rend the air, and in the ether we have those violent magnetic commotions that occur coincidently with some flaming outburst on the Sun.

Hurricane maxima are confined to summer months, and

;reatest number of magnetic disturbances to every tenth —both periodic.

n addition to these analogies, there is in the ether that but well-marked movement which waxes and wanes in *ar* day like the tides of ocean; the moderate perturba- that accompany auroral displays; and that grand move- : whose cycle requires hundreds of years to complete.

'he ether atmosphere is in truth like the air and sea, : up of billows, waves, and ripples; and it is their move- that magnetic instruments record.

9. The direction in space of a freely suspended needle. a knitting-needle be suspended by a silken fibre attached s center of gravity, it will move about freely and at last : to rest without preference for any direction: its mass mmetrically distributed around the point of suspension, therefore no force acts to cause it to take one position :r than another.

}ut place the needle between the poles of a horseshoe romagnet and start the current for a few seconds: now ›ve the electromagnet and let the needle hang by its ; it will not, as previously, be indifferent as to direction, vill take a definite one, from which it can be moved only slight effort, and to which it will quickly return when ceases.

\ new condition has been imparted to the needle by the ric shock, and it is now a magnet wholly under the influ- of the Earth's magnetism.

f this needle, suspended as before, be carried to different ›ns on the globe, its direction and the force holding it in direction will vary from place to place. The magnetism ıe needle may be considered constant during such a ıey, so that the experimental results present a compara- view of the Earth's magnetic condition.

o. Variation, Dip, and Intensity defined.—The needle ;s freely in space, and its direction is defined by reference

to coördinate planes. To be explicit, consider Fig. 152: *F* is a site of observation, say San Francisco; the needle takes the direction *NS* (its lower half, *FN*, need only be considered, for, with obvious modifications, everything stated regarding it becomes equally applicable to the upper half, *FS*); *HFN* is the vertical plane through the needle *NS*, and *MFH* the horizontal plane at *F*; *FH*, the projection of *FN* into the horizontal plane, is the magnetic meridian, into which the needle would settle if a suitable weight were placed on its upper end *S*, to balance the force of terrestrial magnetism; *MF* is the geographical meridian, making the angle *MFH* with the magnetic meridian.

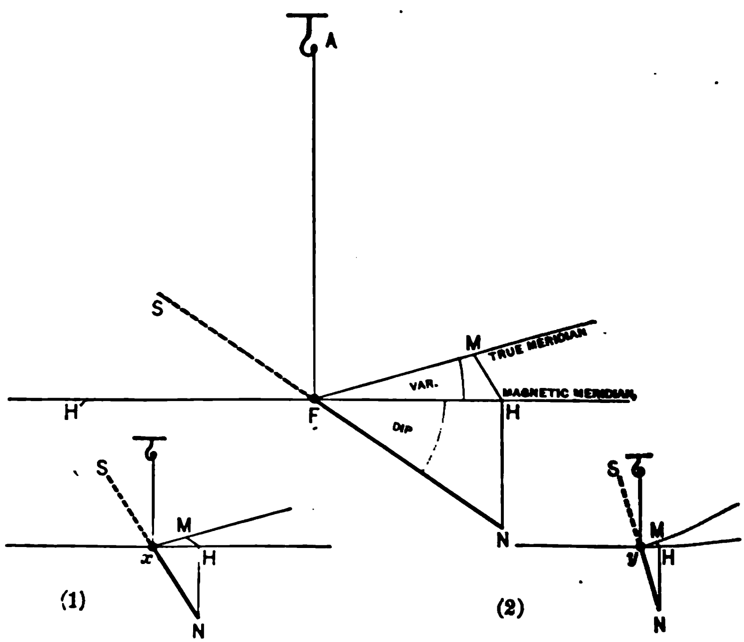


FIG. 152.

The angle *HFN* is called the Dip—it defines the direction of the needle with reference to the horizontal plane, and its present value at San Francisco is 62° 20′; the angle *MFH* is called the Variation—it defines the direction of the needle

with reference to the vertical plane through the geographical meridian of the place, and at present the *projection, FH*, of the needle on the horizontal plane has a variation of 16° 42′ east of the true meridian of San Francisco: both these angles have received other names, but Variation and Dip are familiar to the seaman and will alone be used throughout this Treatise.

The force that holds the needle in the direction SN is called the Total Intensity, and this with the Variation and Dip completely define the magnetic condition of the Earth at any point and date for which they are observed: they constitute the Magnetic Elements. The total intensity at present at San Francisco is 0.54 dyne.

91. A concrete idea of Intensity—merely an illustration.—In passing, it may be said that magnetic intensity can be represented by a weight—gravity balanced against magnetism. If small weights be attached to the needle at S until it turns from its natural direction into one at right angles thereto (still in the vertical plane), the sum of these will be in equilibrium with the total attractive force of the Earth, and be (so to speak) the weight, in parts of a gramme, of that force; at other stations, different weights will be required to produce the same effect, viz., rotate the needle in the vertical plane to a position at right angles to its natural direction, and thus we may obtain the relative weights of magnetic intensity for as many stations as we please.

Similarly, if only sufficient weight be applied to turn the needle at each station into the horizontal position, HH', these weights also would vary from point to point of the Earth, and they would indicate the relative Vertical Intensity of those points; the weight at any station might be represented by the line NH.

And if, at each station, while the needle lay horizontally in the magnetic meridian, FH, a silk fiber were attached to its end, at H, and passed over a delicate little wheel at the

side, and weights were suspended from the free end of the fiber until the needle were drawn into a position in the horizontal plane at right angles to the magnetic meridian, the weights so attached would differ from station to station, and they would denote the relative Horizontal Intensity at the stations; the weight at any station might be represented by the line *FH*.

Table 1 contains the magnetic elements for various cities, widely distributed, and it will be noted how much they differ from one to the other.

TABLE 1.

MAGNETIC ELEMENTS (APPROXIMATELY) FOR THE YEAR 1900.

1	2	3	4	5	6
			Intensity in C.G.S. units.		
Locality.	Variation, *V*	Dip, *D*.	Total Intensity, *T*	Horizontal Component, *H*	Vertical Component, *Z*
New York	9° 12′ W.	70° 06′ N.	0.61	0.2184	0.5732
Washington, D.C	4 35 W.	70 18 N.	0.60	0.2023	0.5650
San Francisco, Cal	16 42 E.	62 20 N.	0.54	0.2507	0.4783
City of Mexico	8 00 E.	45 01 N.	0.48	0.3393	0.3395
St. Petersburg, Russia	0 30 E.	70 46 N.	0.48	0.1581	0.4532
Paris, France	14 30 W.	64 55 N.	0.47	0.1992	0.4257
London, England	16 16 W.	67 09 N.	0.47	0.1841	0.4369
Rome, Italy	10 00 W.	58 00 N.	0.45	0.2384	0.3816
Tokio, Japan	4 06 W.	49 52 N.	0.45	0.2901	0.3440
Bombay, India	0 36 E.	20 38 N.	0.37	0.3462	0.1304
St. Helena Island	25 00 W.	32 12 S.	0.31	0.2623	0.1652
Cape Town, So. Africa	29 24 W.	58 02 S.	0.36	0.1906	0.3054
Sydney, Australia	9 36 E.	62 45 S.	0.57	0.2610	0.5067
Hobartown, Tasmania	25 00 E.	71 12 S.	0.64	0.2062	0.6059

Arranged according to values of the Total Intensity from North to South.

It need hardly be said that the intensity is *not* determined in the way described above—that was merely for illustration,

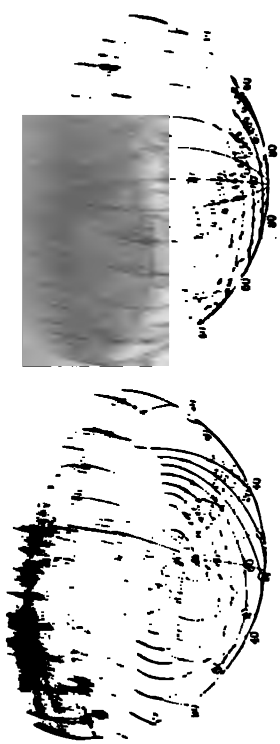
to convey an idea beyond the mere abstract one of the word itself; and it is seldom that the total intensity is observed directly: it is more convenient to observe the horizontal intensity, and from this and the observed dip, to calculate the total intensity and its vertical component.

92. How data of the elements are obtained: magnetic charts.—From ships of war cruising in every sea; from merchant vessels plying between the ports of the world; from observatories equipped with delicate instruments in various countries; from expeditions afloat and ashore specially fitted out for the purpose; and from numerous other private and public sources of many kinds, have been gathered, during long years, a multitude of observations of the magnetic elements: collated, classified, and stripped of all discernible errors, they afford, when plotted on charts of the globe, an excellent insight into its magnetic condition. This is presented in Charts I to V, each exhibiting the characteristic features of a single element. These features are portrayed by drawing lines through points having the same value of the element in question: in Charts I, IV, and V the lines of *equal* intensity, whether total, horizontal, or vertical, are expressed in C.G.S. units; these are absolute units, dependent only on certain standards of length, weight, and time, and not at all on locality. These same lines, however, are often represented on charts by other figures, dependent on some one place arbitrarily chosen as unity: such is a system, in which the intensity at London is assumed as *unity*, and that of every other place is relative to this; such, also, is the system of Humboldt, whose site with which to compare the rest of the world was located in Peru. In Charts II and III the lines of equal Variation and Dip are expressed in degrees.

93. Features that magnetic charts exhibit: meaning of North and South Poles.—Glancing at Chart I, it will be seen that there is a region of maximum total intensity in the northern hemisphere and another in the southern—that in

side, and weights were s... fiber until the needle we... zontal plane at right an... weights so attached wo... they would denote the ... stations; the weight at ... the line *FH*.

Table I contains the ... widely distributed, and ... from one to the other.



MAGNETIC F...
F...

I

Locality.
New York..............
Washington, D. C...
San Francisco, Cal....
City of Mexico.......
St. Petersburg, Russia..
Paris, France........
London, England....
Rome, Italy..........
Tokio, Japan..........
Bombay, India.......
St. Helena Island....
Cape Town, So. Afri..
Sydney, Australia. ..
Hobartown, Tasman...

Arranged accord... South.

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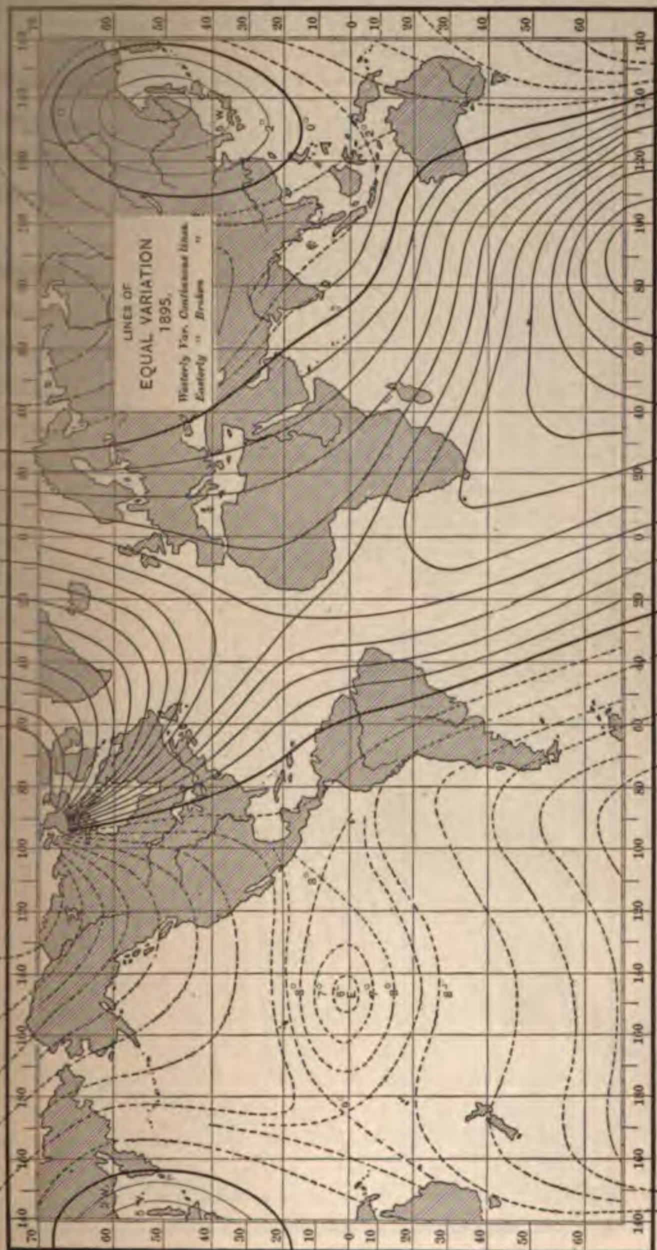

LINES OF
EQUAL VARIATION
1895.

CHART III.
LINES OF EQUAL DIP.

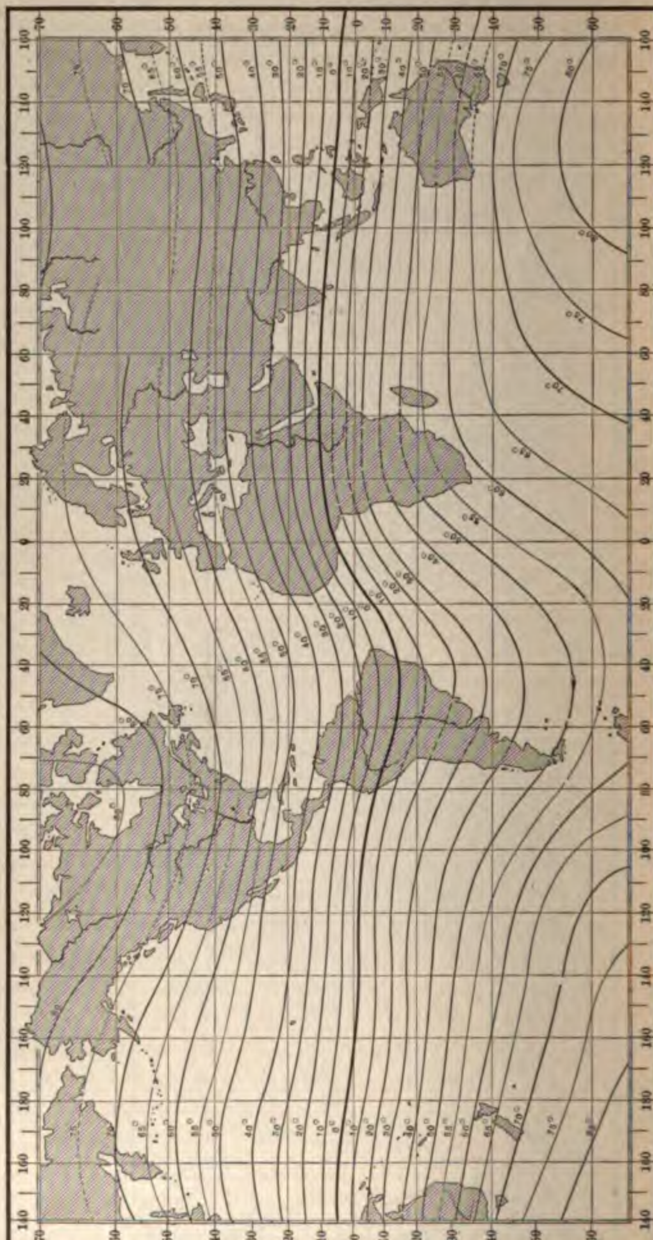
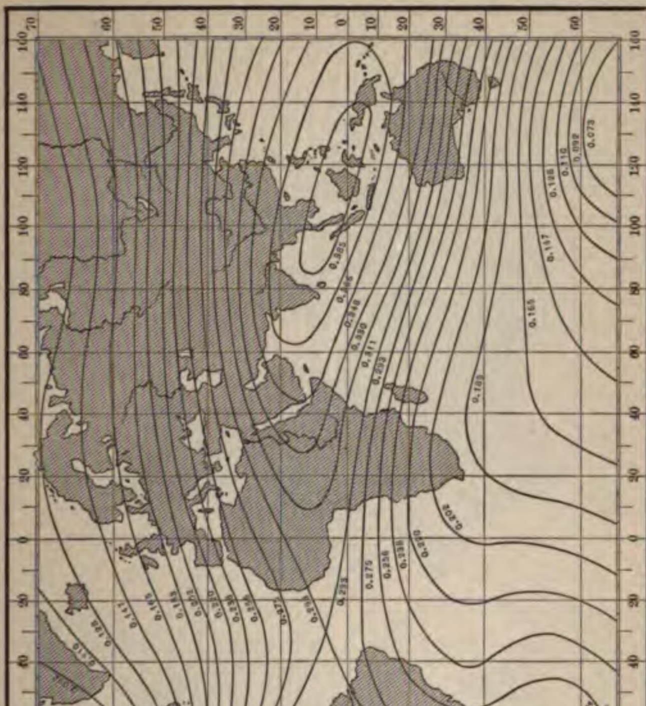


CHART IV.

LINES OF EQUAL HORIZONTAL INTENSITY.



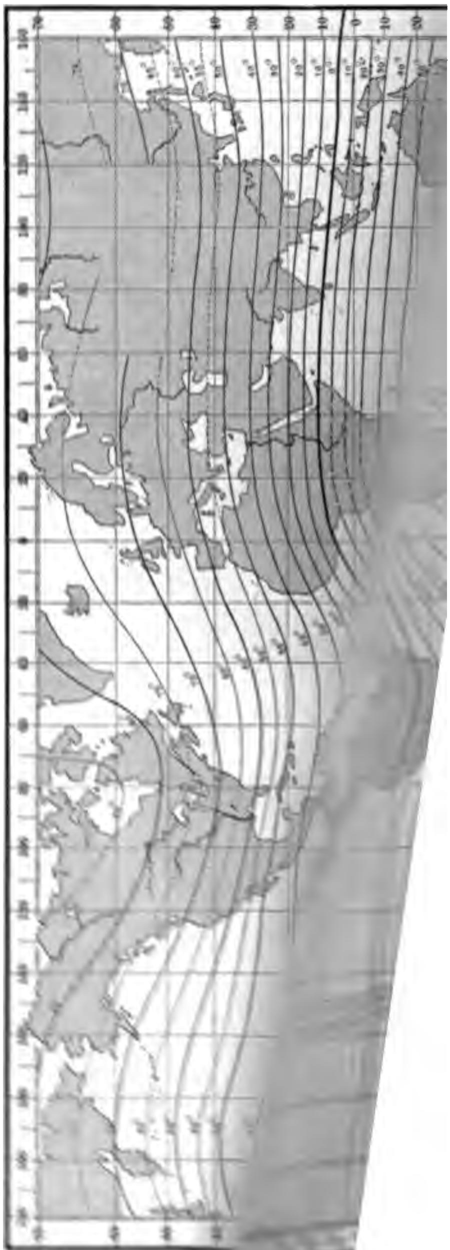
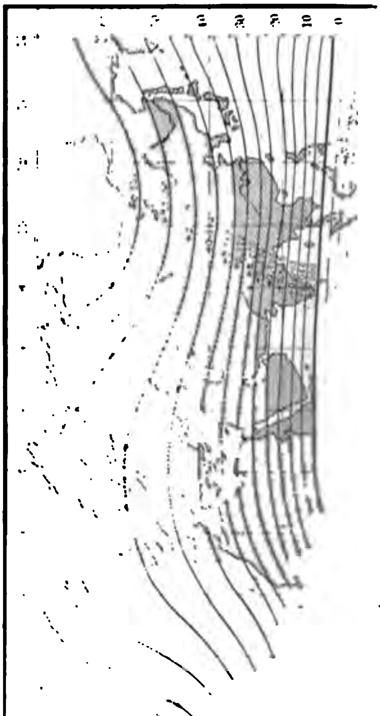


CHART III.
Lines of Equal Dip.

each region there are two foci or restricted areas more intense than the rest of the region—and that these foci are widely separated in the north, but close together in the south, which explains the greater strength of the latter compared with the former; between these extremes the total intensity, represented in gradient lines, decreases as we approach the tropical zone, where a line encircles the globe, dividing it into two characteristic parts, just as the neutral section does the opposite poles of a magnet: the Earth is clearly a spherical magnet, of irregular distribution.

The foci of greatest total intensity are *near* what are called the *magnetic poles*, but they are not the same thing: the foci of intensity are places where the magnetic condition on the Earth's surface is most concentrated; the magnetic poles, where the dipping-needle stands vertical (the horizontal force being nil), and from which the lines of equal dip (see Chart III) spread out like ripples from a center. The lines of equal force that belong to the foci of intensity, gird the Earth in close proximity to those of equal dip, but both series are not coincident. The magnetic equator is the median line of no dip, north of which one end of a freely suspended needle will dip below the horizontal plane, and south of which the other end will act similarly. The "magnetic poles" are really poles of "verticity," but as long as the distinction between them and those of intensity is clearly understood, they may continue to be called magnetic poles. It is like the designation *North* and *South* applied to them as well as to the ends of the needle that point to them: we may still follow the custom that long usage has indelibly stamped on the mind, and call both the terrestrial magnetic pole and the end of the compass-needle that points to it by the *same name*—North or South—provided we keep in view the fact that the magnetic conditions of the pole and the end of the compass-needle pointing to it are the direct opposite of each other.



...ing than intro-
... are designed to

...th the foregoing
...thern hemisphere
...rmity with time-
...gnetic Pole, and
...ward it, the *North*
... magnetic pole in
... 05′ N. and longi-
...–1843, he reached
... 50′, from which he
... pole to be in lati-

...al variation, it will
...aced by two heavy
... the Variation is
...etween these, the
...them, easterly; ex-
... Asia, where it is

... intensity.
... show
... middle

... and its Horizontal

..l than in another. Consider in this
..n: at San Francisco, *F*, the needle
..rizontal component, *FH*, has a good
.. Alaska, as at *x*, Fig. 152—(1), it dips
..ntal component, *xH*, is less; continuing
..ctic Ocean, as at *y*, Fig. 152—(2), it dips
..re is scarcely enough of the horizontal
.. give the needle a definite direction.

Variation—its Discovery and Fluctuations.

..**movements.**—The ether is in ceaseless agi-
..magnetic elements, like facial features, be-
..thereby and give expression to every passing

..ents have been grouped according to certain
.. by hours, whence we learn their diurnal
..nths, whence the annual; and by years, whence
..at slow, majestic stride that covers centuries.
.. movements of abnormal amount—called dis-
.. have been bunched together and found to
.. recurrence; there is the movement peculiar
..ay: the particular value that the elements have
..contrasted with that of summer in the same
..ir distinctive aspect in the northern hemisphere
..hour, day, month, or season as compared with
..uthern.

..d upon all these are other small regular mo-
.. upon waves and billows.

..**rical.**—The discovery of the Variation may
..ncident with the use of the magnetic needle for
..course; for the trend of that course relative to
..of the Pole Star, which was the initial point of
..ning before the Sun became generally used for

It is better to have this tacit understan
duce confusion by the variety of names that
describe the exact state of affairs.

The old names lead to no error, and wit
explanation, the pole of verticity in the nort
will (throughout this Treatise), in conforn
honored usage, be called the *North* Mag
the point of the Compass that is directed tow
point. Sir James Ross reached the north n
1831, and found the dip 90° in latitude 70° o
tude 96° 45′ W.; during his cruise in 1839-1
a southern point where the dip was 88° 56′,
inferred the location of the south magnetic
tude 73° 05′ S. and longitude 147° 05′ E.

In Chart II, representing lines of equa
be seen that a strip of the globe is embra
lines running N.W. and S.E., along whi
zero, or they are lines of "no Variation":
Variation is constantly westerly—outside
cept within an oval area in the N.E. par
again westerly.

Chart IV, representing lines of equ
is especially worthy of consideration, a
the Compass experiences a strong dir
latitudes, while it becomes sluggish in

There are two small oval areas o
Borneo, the other south of Mexico: l
imum *horizontal* intensity—sloping
contour "level-lines" spread out n
vanish in a flat plane round the reg

**94. Variability of the Total Int
Component.**—The *total* intensity i
Pole—its *horizontal* component fr
is this latter that gives to the C
hence it becomes evident why th

and that thence onward the number of magnetic observations spread and increased slowly but steadily in all countries until 1800, when they sprang into existence everywhere and multiplied in kind, number, and variety to such extent that to-day no phenomenon of Nature is the object of more frequent and close scrutiny than terrestrial magnetism. At sea, the ships of every nation are daily observing its fluctuations, and on land there are numerous observatories specially built and supplied with the most delicate instruments for recording by photography its every phase.

97. The Variation observed at sea by officers of the U. S. Navy.—I will state here the part taken by officers of the U. S. Navy in this field of research during recent years.

While Superintendent of Compasses in the Bureau of Navigation, Navy Department, from 1881 to 1885, I conceived the idea of making use of the compass errors that are daily observed by navigators of ships. This plan required each vessel to swing ship on as many equidistant points as practicable at the beginning and end of a passage and at every change of 15° to 20° of latitude or longitude *en route*.

The *variations* deduced from such *swingings* (in view of the care bestowed on them, the favorable conditions of sea and weather chosen for the work, and the accuracy of the instruments used) are probably among the most reliable ever obtained from sea observations.

Among the blank forms devised at the time to facilitate compass work was number I (essentially the same used at the present day) and upon it was provided the space headed "Record of all the most trustworthy compass errors determined for navigating the ship": the deviation tables obtained from swinging ship at intervals along the passage afforded the means of removing the deviation from each compass error, and thus obtaining a number of trustworthy variations, whose accuracy was further enhanced by the fact that, with few exceptions, the ships of the Navy during the

time referred to, were of wood, giving rise to small deviations, liable to little change.

Where ships made particularly long passages or to unfrequented regions, special instructions regarding compass observations were sent to them by the Chief of the Bureau of Navigation: such was the case with the ALLIANCE, BEAR, and THETIS sent to the Arctic; the TRENTON and ESSEX to China; the BROOKLYN returning home from Japan, *via* Cape Horn; the ENTERPRISE to Australia and home; the JUNIATA from China home; the VANDALIA, SWATARA, and RICHMOND, cruising; and the PENSACOLA around the world. This last ship made a very full series of observations: sailing from Callao, Peru, for Japan and thence home by way of the Cape of Good Hope, the ship was swung at Callao before sailing; off the Capes of the Chesapeake on arrival; and at twelve spaced intervals along the passage.

The total number of Variations obtained from all vessels was 13,[illegible] collected from ships that had traversed every sea, and approached the Poles to within 79° 54′ North and 51° 50′ South; the observations were corrected—some, by the navigators who observed them, but by far the greater number in the office of Supt. of Compasses, and were all published in Naval Professional Paper No. 19. By a second edition the work was brought up to 1892, I think.

[illegible] **The Magnetic Observatory at Washington built and equipped.** To supplement this work at sea, I proposed to the Chief of Bureau of Navigation, Rear Admiral John G. Walker, the erection of a Magnetic Observatory in Washington. He favored the project, obtained an appropriation for it, and authorized me to proceed with the plans for the building and its equipment with instruments.

The Government at that time had no instruments of the kind used in observatories for the continuous record of the magnetic elements, so a complete set of the large and improved magnetographs was ordered through the Kew (Eng-

land) Observatory, that pattern being the one most generally used throughout the world.

The Bureau already possessed an excellent magnetometer for measuring the absolute force and a Dip Circle; and I had a large magnet on Gauss' plan with silken fiber suspension constructed for eye-observation of the Variation: an extremely accurate theodolite was purchased for use in connection with this variation-magnet.

Some minor instruments and appliances were also provided. The magnetographs, on their arrival from England, were set up roughly in the office of the Supt. of Compasses to study their mode of working. There was also provided a full set of apparatus (the counterpart of the set used by Ritchie) for inspecting compasses, which it was my intent to do in the Magnetic Observatory.

The plans for the building were complete, and the kind, number, and location of the instruments settled and specified by drawings and descriptions; but, on account of long and serious sickness in my family, I had to apply for leave of absence, and leave Washington before seeing the completion of the project. Besides, I had been on the duty for four years, and it was doubtful, in any case, if I could have remained long enough to see actual observations made with the several instruments.

My relief, Commander C. C. Cornwell, assisted by other officers of the Navy, supervised the erection of the building, installed the instruments, and began observations with them. The results, published since, are evidence of the value of the Magnetic Observatory.

It was built on the site of the old Naval Observatory in Washington, but on removal of the latter to Georgetown, the building, instruments, and all other material of the Magnetic Observatory were transferred too, and are now on the new site as part of the Naval Observatory.

99. The secular change in the Variation.—The different periodic changes of the Variation will now be described; and first the *secular*, as of primary importance, for upon an accurate knowledge of it depends the correctness of the variation charts that are used in navigation.

The secular change consists of a steady increase or decrease of the Variation at any place: it goes on for many years—the needle attains its greatest deflection from the *true* meridian (or the Variation becomes a maximum)—there it oscillates in small amount for a few years—then turns back—attains a maximum deflection in the opposite direction—quivers slowly as before for a time—and then returns to its first position. And so on—back and forth—over a certain range of degrees during a long period of time. The motion may be likened to the swing of a pendulum, which has slow movement at the extremes of its amplitude and rapid pace at the middle point—a wave-motion, in fact. Thus the secular change being a periodic function of the time, may be fully developed by Fourier's series; and hence it becomes possible to predict with safety for a few years ahead (from deduction from the theorem) the value of the Variation at any [illegible] for which accurate observations have extended over [illegible] time to furnish the known quantities required for [illegible] of the series. These quantities are the sign-posts for [illegible] guidance in using the series, and they must be [illegible] closely and changed often to keep us in the right [illegible].

[illegible] analytical treatment of the Variation is not restricted [illegible] element, but may be extended to the Dip and In[illegible] long observation shows them to be periodic functions of the time.

[illegible] centuries for the magnetic pendulum to com[illegible] swing, and although observation of the Variation has [illegible] for more than three hundred years at some [illegible] the Earth, yet not even at these has one cycle been

completed. This cycle, as well as the maximum deflection that occurs during its fulfillment, together with the annual contribution thereto, all vary greatly from place to place.

TABLE 2.

SECULAR CHANGE IN THE VARIATION.

NEW YORK.

Year.	Variation.	Year.	Variation.	Year.	Variation.
1580	10° W.	1775	7° W.	1847	5° 41′ W.
1610	11 W.	1789	4 20′ W.	1855	6 28 W.
1625	11 30′ W.	1824	4 40 W.	1860	6 44 W.
1680	12 W.	1833	3 W.	1872	8 46 W.
1684	8 25 W.	1834	4 50 W.	1873	7 29 W.
1686	9 W.	1837	5 40 W.	1874	7 23 W.
1691	8 25 W.	1840	5 45 W.	1879	7 52 W.
1700	8 20 W.	1841	6 W.	1884	7 25 W.
1714	8 15 W.	1842	5 52 W.	1885	8 10 W.
1724	7 20 W.	1844	6 13 W.	1890	8 27 W.
1750	6 W.	1845	6 25 W.	1895	8 44 W.
1755	5 W.	1846	5 09 W.		

Tables 2, 3, 4, and 5 in connection with Figs. 153, 154, 155, and 156, illustrate the *secular* change at divers parts of the Earth from the most remote period of observation of the Variation at each, to the present epoch.

In these Figures the movement of a *horizontal* needle is depicted by rectangular coördinates—the time at the side, the range of variation proper to the locality at the top.

The dots indicate actual observations plotted from the tables, while the curves take a middle course through them.

Glancing at Table 2, illustrated by Fig. 153, it will be seen by the path of the north end of a needle at New York, that when first observed in 1580, the variation was 10° W.; this increased until 1680; then the needle took a long stride eastward, gradually lessening the variation to 3°, when, in 1833, again it turned westward, and is still moving in that direction.

SECULAR CHANGE OF THE VARIATION AT NEW YORK.
SCALE OF VARIATION.

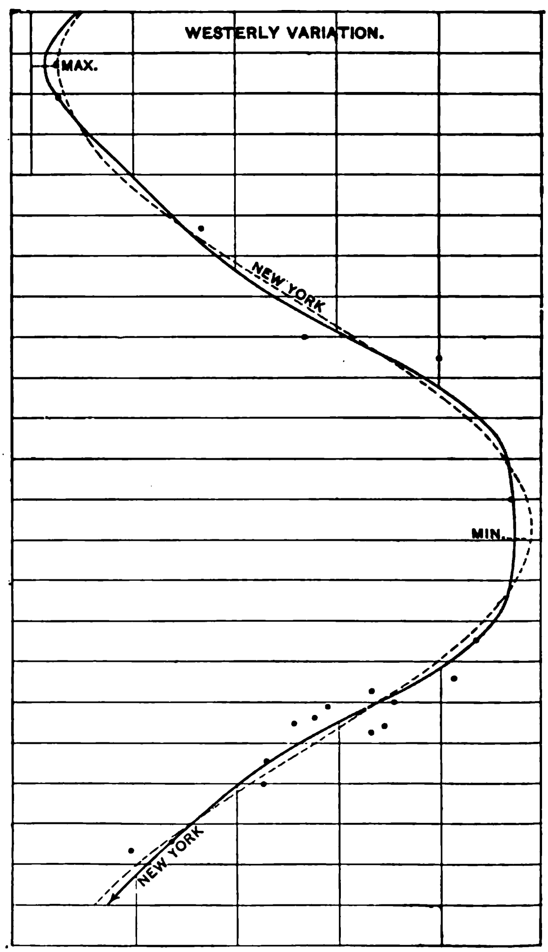


FIG. 153.

differences between the Variation of successive years ecular change—afford the data for correcting charts blishing them with sufficient accuracy for a few years

e first observed, the secular change at New York has 1 increase or decrease of *westerly* variation; but now r the movement at Paris, France, Fig. 154, in connec-

TABLE 3.

SECULAR CHANGE IN THE VARIATION.

PARIS, FRANCE.

Variation.	Year.	Variation.	Year.	Variation.
7° E.	1710	11° 11' W.	1812	22° 29' W.
8 E.	1720	12 52 W.	1816	22 26 W.
11 30' E.	1726	14 37 W.	1827	22 15 W.
8 45 E.	1735	15 23 W.	1835	22 04 W.
8 00 E.	1744	16 37 W.	1838	21 38 W.
4 30 E.	1753	17 49 W.	1842	21 . 29 W.
2 30 E.	1765	19 W.	1858	19 36 W.
1 30 E.	1770	20 01 W.	1865	18 44 W.
0 40 E.	1777	20 40 W.	1869	17 08 W.
0 08 W.	1782	21 25 W.	1875	17 21 W.
1 30 W.	1790	22 18 W.	1879	16 56 W.
3 08 W.	1798	22 14 W.	1885	16 07 W.
4 52 W.	1802	21 58 W.	1888	15 52 W.
6 37 W.	1805	22 05 W.		
9 W.	1807	22 34 W.		

th Table 3: there, in 1541, the variation was 7° E., easing and kept on so until 1580; then a grand retro- novement began and continued for 234 years, the eaching the *true* meridian about 1666, passing to the it and advancing in that direction until 1814, when iation was more than 22° W.; again it turned east- nd is still moving to the east, to complete its cycle.

secular changes at Hobartown, Tasmania, and the Good Hope, Africa, are given in Tables 4 and 5: with

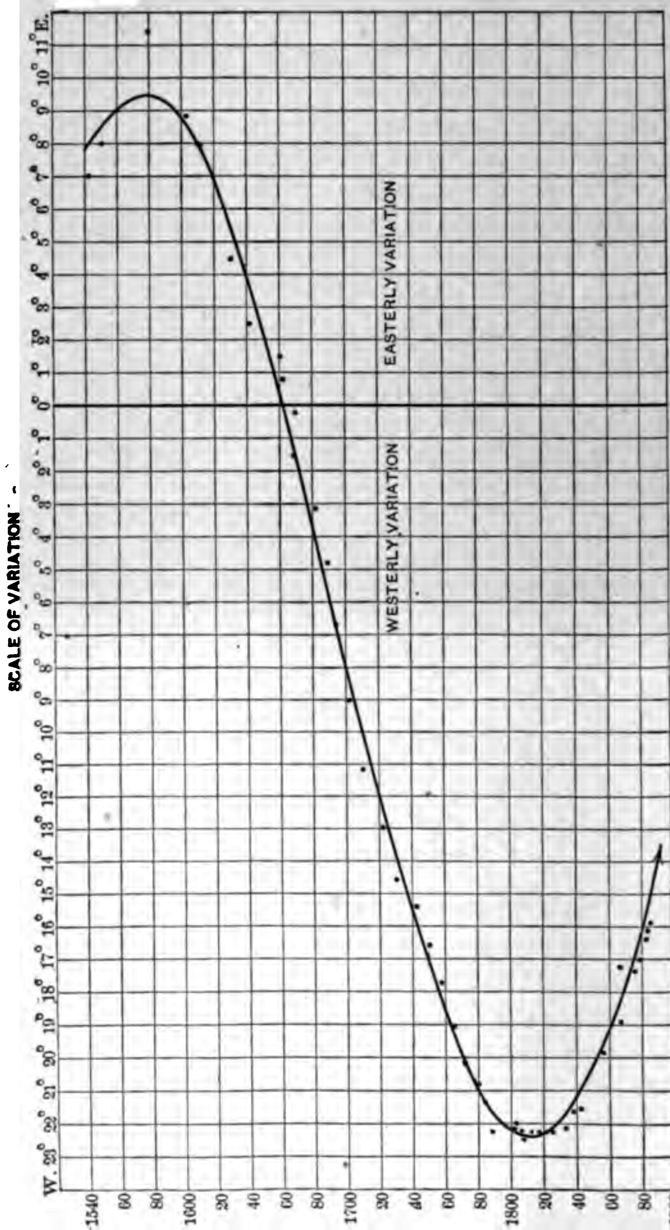

SCALE OF VARIATION
EASTERLY VARIATION
WESTERLY VARIATION
W. 23° 22° 21° 20° 19° 18° 17° 16° 15° 14° 13° 12° 11° 10° 9° 8° 7° 6° 5° 4° 3° 2° 1° 0° 1° 2° 3° 4° 5° 6° 7° 8° 9° 10° 11° E.
1540 60 80 1600 20 40 60 80 1700 20 40 60 80 1800 20 40 60 80 1900

FIG. 154.

Figs. 155 and 156, drawn from them, they afford a means of contrasting the phenomenon in southern regions with that in northern.

SECULAR CHANGE IN THE VARIATION.

TABLE 4. CAPE OF GOOD HOPE, AFRICA.				TABLE 5. HOBARTOWN, TASMANIA.	
Year.	Variation.	Year.	Variation.	Year.	Variation.
1605	0° 30′ E.	1839	29° 09′ W.	1843	9° 54′ E.
1609	0 12 W.	1841	29 06 W.	1844	9 55 E.
1622	2 00 W.	1845	29 08 W.	1845	9 57 E.
1675	8 14 W.	1846	29 09 W.	1846	9 58 E.
1691	11 00 W.	1847	29 12 W.	1847	9 59 E.
1751	19 15 W.	1848	29 14 W.	1848	10 01 E.
1775	21 14 W.	1849	29 16 W.		
1788	24 04 W.	1850	29 19 W.		
1792	24 31 W.	1857	29 34 W.		
1818	26 31 W.	1874	30 04 W.		
1836	28 30 W.	1890	29 36 W.		

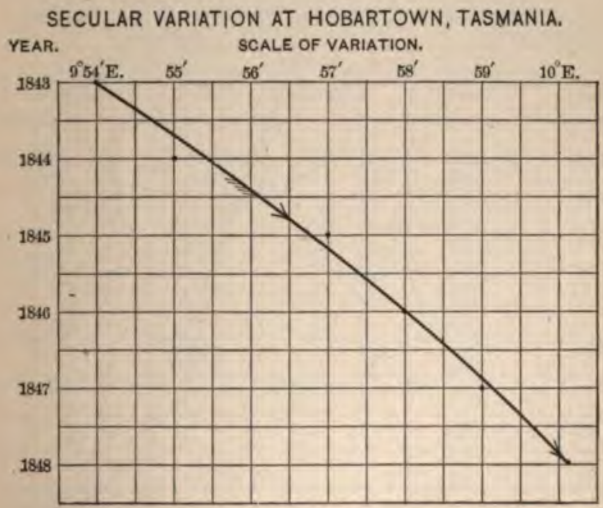


FIG. 156.

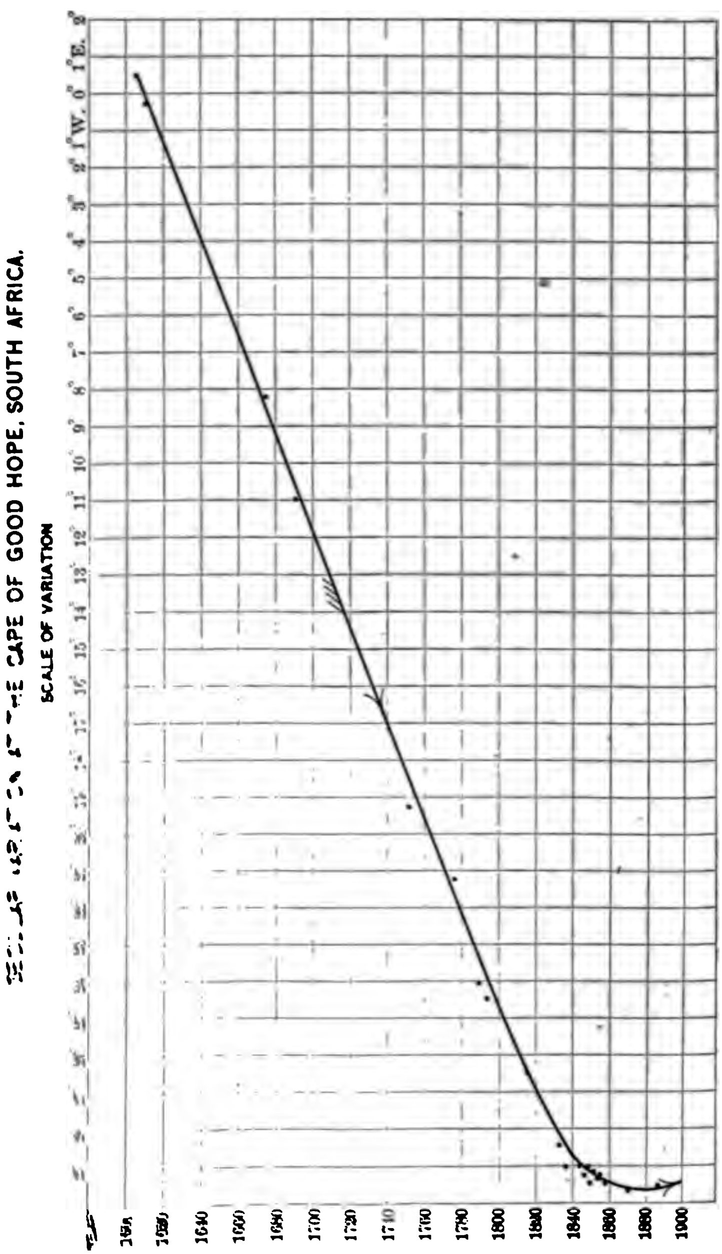
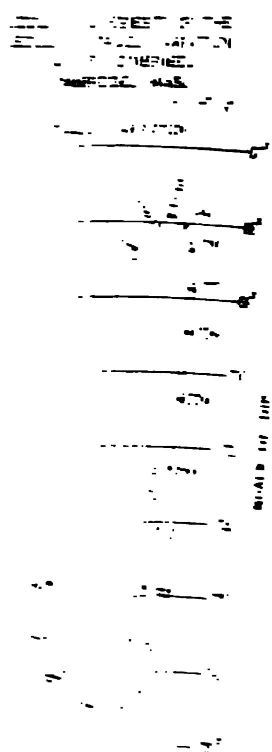

CAPE OF GOOD HOPE, SOUTH AFRICA.
SCALE OF VARIATION
1640
1660
1680
1700
1720
1740
1760
1780
1800
1820
1840
1860
1880
1900

FIG. 155.

100. Movement of the magnetic needle in space graphically represented.—The movement of a needle in a horizontal plane (which is that graphically represented in the four cases of Art. 99) does not give a clear idea of the motion of a needle *not* so constrained: to obtain this and depict it, imagine a freely suspended needle at the center of a spherical surface; it moves in both Dip and Variation at the same time, and each end traces out on the interior of the surrounding shell a closed curve of identical form; let a plane be passed tangent to the sphere at the point in which the suspending fiber pierces it, then the closed curve may be projected on this plane, and such in principle is the mode of representation in Figs. 157, 158, and 159: the observations of Variation and Dip in Tables 6 to 11 afford the means of plotting the points of the curves.

CAMBRIDGE, MASS.

Table 6. Secular change in the Variation.				Table 7. Secular change in the Dip.	
Year.	Variation.	Year.	Variation.	Year.	Dip.
1708	9° 00′ W.	1840	9° 18′ W.	1722	68° 22′ N.
1742	8 00 W.	1842	9 35 W.	1780	69 51 N.
1750	7 42 W.	1844	9 39 W.	1782	69 41 N.
1757	7 20 W.	1845	9 32 W.	1783	69 41 N.
1761	7 14 W.	1850	9 30 W.	1839	74 20 N.
1763	7 00 W.	1852	10 08 W.	1840	74 22 N.
1780	7 02 W.	1854	10 39 W.	1841	74 17 N.
1782	6 44 W.	1855	10 55 W.	1842	74 16 N.
1783	6 52 W.	1856	10 50 W.	1844	74 18 N.
1788	6 38 W.	1859	10 48 W.	1845	74 19 N.
1810	7 30 W.	1866	10 41 W.	1850	74 34 N.
1833	8 00 W.	1879	11 46 W.	1854	74 33 N.
1835	8 51 W.	1895	12 22 W.	1856	74 12 N.
1837	9 09 W.			1859	74 20 N.
				1879	73 48 N.
				1895	73 16 N.



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ACAPULCO, MEXICO.

TABLE 8. SECULAR CHANGE IN THE VARIATION.				TABLE 9. SECULAR CHANGE IN THE DIP.	
Year.	Variation.	Year.	Variation.	Year.	Dip.
1625	1° 30′ E.	1841	8° 17′ E.	1791	36° 08′ N.
1744	3 00 E.	1866	8 22 E.	1803	38 53 N.
1791	7 44 E.	1874	8 39 E.	1838	37 57 N.
1822	8 40 E.	1880	7 57 E.	1866	39 54 N.
1828	9 07 E.	1882	7 54 E.	1880	40 09 N.
1837	8 23 E.	1892	7 35 E.	1892	40 25 N.
1838	8 15 E.				

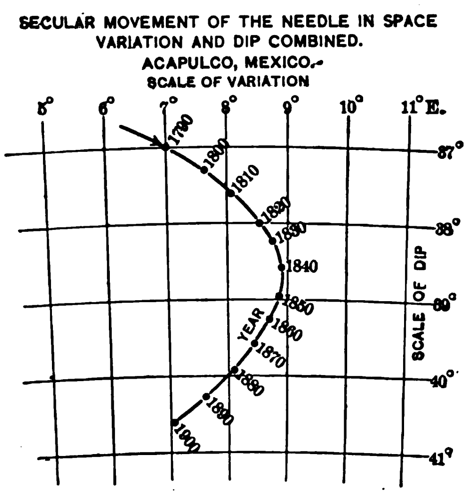


FIG. 158.

SE[illegible]
NE[illegible]

W. 1[illegible]

[illegible] THE DIP.

	Year	Dip.
[illegible]	[illegible]	[illegible] N.
N.	[illegible]	[illegible] N.
N.	[illegible]	[illegible] N.
N.	[illegible]	[illegible] 52 N.
N.	[illegible]	[illegible] 51 N.
N.	[illegible]	[illegible] 47 N.
N.	1877	70 49 N.
N.	1878	70 48 N.
N.	1870	70 48 N.
N.	1880	70 45 N.
N.	1881	70 43 N.
N.	1882	70 44 N.
N.	1883	70 41 N.
N.	1884	70 35 N.
N.	1885	70 33 N.
N.	1886	70 30 N.
[illegible]	1887	70 27 N.
[illegible]	1888	70 25 N.
[illegible]	1889	70 25 N.
[illegible]	[illegible]	70 24 N.
[illegible]	[illegible]	70 24 N.
[illegible]	[illegible]	70 21 N.
[illegible]	[illegible]	70 12 N.
[illegible]	[illegible]	70 15 N.

It will be [illegible]
bridge, Acap[illegible]
curve, all hav[illegible]
needle moves
none has the
servation—th[illegible]

101. The annual change in the Variation.—The *annual* change in the Variation is a periodic fluctuation during the months of the year, and seldom attains 2′ of arc: it is illustrated by Table 12: the prominent fact brought out is, that

TABLE 12.

FLUCTUATION OF THE VARIATION THROUGHOUT THE MONTHS OF THE YEAR AT DIFFERENT PLACES.

Months.	Amount and direction of the change on each side of the mean for the year: Plus (+) denotes that the needle is to the eastward, minus (−) to the westward, of the mean position for the year.				
	Kew, England.	Canada. Toronto,	St. Helena Island.	Cape of Good Hope. South Africa.	Hobartown, Tasmania.
January	− 2″.6	− 4″.2	+ 3″.0	− 29″.4	− 32″.9
February	− 34 .2	− 0 .6	− 18 .0	− 43 .2	− 7 .9
March	− 29 .8	+ 7 .8	− 10 .2	− 49 .8	− 16 .7
April	− 1 .5	+ 0 .6	+ 2 .4	− 64 .2	+ 22 .2
May	+ 48 .8	+ 9 .6	+ 1 .2	+ 10 .8	+ 28 .7
June	+ 50 .6	+ 17 .4	+ 13 .8	+ 62 .4	+ 24 .1
July	+ 70 .3	+ 42 .6	− 8 .4	+ 58 .2	+ 20 .6
August	+ 20 .7	+ 4 .2	+ 3 .6	+ 61 .8	+ 12 .2
September	− 9 .8	− 47 .4	+ 19 .8	+ 43 .2	+ 4 .5
October	− 49 .6	− 61 .0	− 1 .8	+ 4 .8	− 13 .6
November	− 34 .8	− 24 .6	− 7 .2	− 25 .2	− 27 .6
December	− 39 .6	− 19 .8	− 7 .2	− 42 .6	− 38 .5

TABLE 13.

FLUCTUATION OF THE VARIATION ACCORDING TO SEASON.

(Rearrangement of Table 12.)

Locality.	Mean Value of the Fluctuation and its Direction.	
	April to September.	October to March.
Kew	+ 28″.7	− 31″.8
Toronto	+ 4 .5	− 17 .1
St. Helena	+ 5 .4	− 6 .9
Cape of Good Hope.	+ 28 .7	− 30 .9
Hobartown	+ 18 .7	− 17 .3

regardless of geographical location, or the amount of the Variation, at a place, or whether it is easterly or westerly, increasing or decreasing, or what the absolute value of the secular change may be—for all these circumstances enter into Table 12—still, the needle is steadily on one side of its mean *yearly* position during the summer months of the locality, while it is on the other side of its mean yearly position during the winter months of the same place, see Fig. 162. The

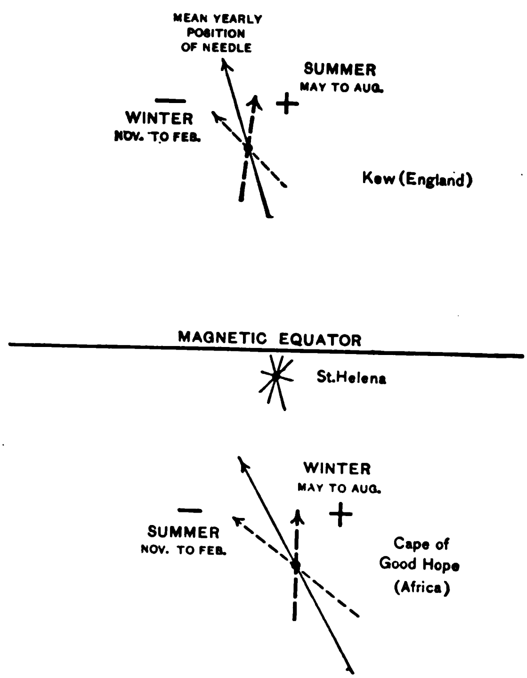


FIG. 162.

change occurs in the equinoctial months, as may be seen by the uncertainty of sign at those times; and St. Helena shows most irregularity in this respect, as it naturally should from its proximity to the magnetic equator.

By taking the mean for each place for each of the two

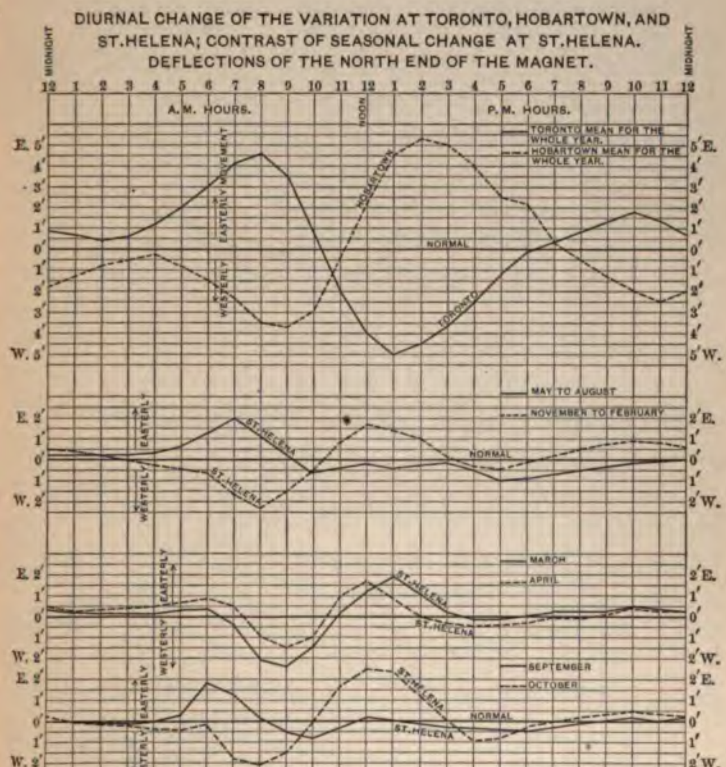
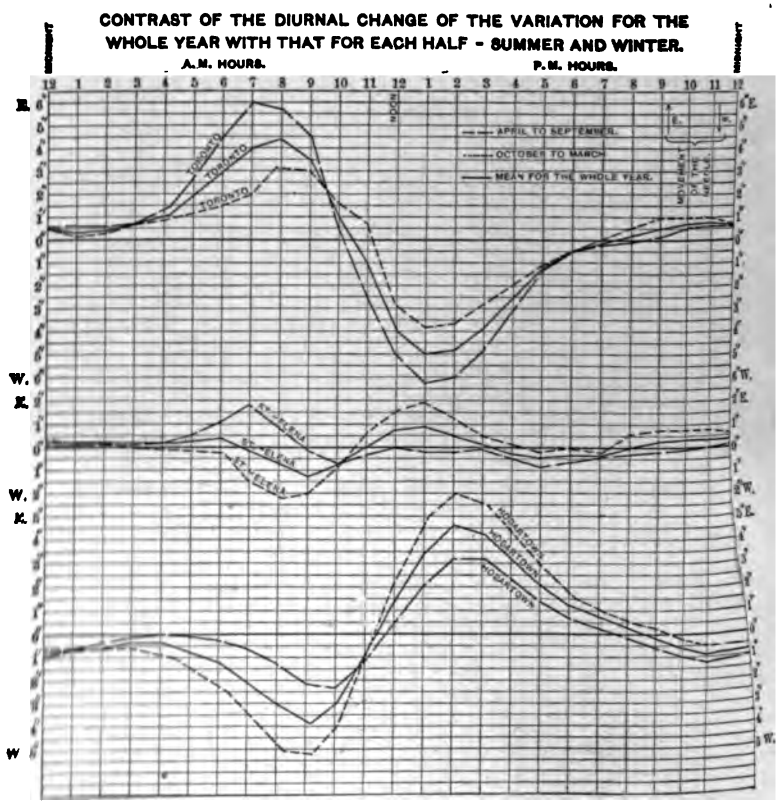

DIURNAL CHANGE OF THE VARIATION AT TORONTO, HOBARTOWN, AND
ST. HELENA; CONTRAST OF SEASONAL CHANGE AT ST. HELENA.
DEFLECTIONS OF THE NORTH END OF THE MAGNET.
MIDNIGHT
A. M. HOURS.
NOON
P. M. HOURS.
TORONTO MEAN FOR THE WHOLE YEAR.
HOBARTOWN MEAN FOR THE WHOLE YEAR.
EASTERLY MOVEMENT
WESTERLY
HOBARTOWN
TORONTO
NORMAL
MAY TO AUGUST
NOVEMBER TO FEBRUARY
ST. HELENA
EASTERLY
WESTERLY
MARCH
APRIL
SEPTEMBER
OCTOBER

FIG. 160.



CONTRAST OF THE DIURNAL CHANGE OF THE VARIATION FOR THE WHOLE YEAR WITH THAT FOR EACH HALF - SUMMER AND WINTER.
MIDNIGHT
A.M. HOURS.
P.M. HOURS.
MIDNIGHT
NOON
APRIL TO SEPTEMBER.
OCTOBER TO MARCH.
MEAN FOR THE WHOLE YEAR.
MOVEMENT OF THE NEEDLE.
TORONTO
TORONTO
TORONTO
ST. HELENA
ST. HELENA
ST. HELENA
HOBARTOWN
HOBARTOWN
HOBARTOWN

FIG. 161.

periods, April to September and October to March, as is done in Table 13, the contrast between the two portions of the year becomes more striking. This clearly shows a dependence of the annual fluctuation upon the position of the Sun with regard to the Equator. The oppositeness of movement of the needle in both magnetic hemispheres according to *season* receives further illustration in Figs. 160 and 161. From them it will be seen that at stations well north or south, as at Toronto and Hobartown, the needle at all seasons maintains a characteristic position with reference to the mean position for the year, only that in the summer of each hemisphere the range is greater than in winter, while at St. Helena, located near the divide, there is alternately the characteristic feature of each hemisphere, according to the position of the Sun.

It can scarcely be inferred, however, that this change in the range of the needle is *wholly* due to TEMPERATURE, for in the vaults of the Paris Observatory, eighty feet below the surface, where the temperature is maintained at a constant, the same seasonal movement is observed.

102. The Diurnal Change in the Variation.—The *diurnal change* in the variation consists of a regular swaying to and fro of the magnetic meridian—twice to the east and twice to the west—during the period of twenty-four hours: it is illustrated in Table 14 for five widely separated stations.

This Table is formed by taking the mean of all the hourly observations during the year, which gives the mean variation for the year; also, the mean for the *same hour* throughout the year, which gives the separate hourly means.

Subtracting each hourly mean from the yearly mean gives a series of values for the twenty-four hours of the day, which are the quantities that appear in Table 14, the plus (+) sign indicating that the north end of the needle was to the east of its mean position, and the minus (—) sign that it was to the west of it. Fig. 163, drawn from Table 14, represents the

TABLE 14.

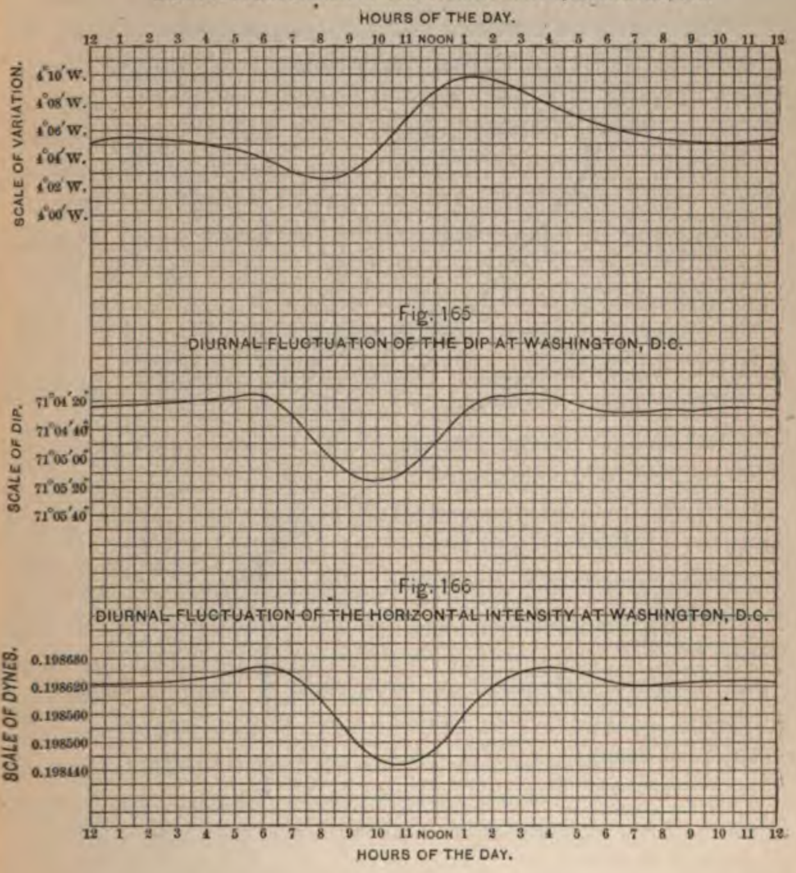
DIURNAL FLUCTUATION OF THE VARIATION AT DIFFERENT PLACES.

Hours.	Name of place, and amount and direction of the fluctuation on each side of the mean position of the needle for the year: plus (+) denotes that the north end of the needle is to the eastward of the mean for the year, and minus (−) that it is to the westward, by the amount opposite the sign.				
	Washington, D. C.	Toronto, Canada.	St. Helena Island.	Cape of Good Hope, South Africa.	Hobartown, Tasmania.
1 A.M.	+ 0'.27	+ 0'.54	+ 0'.13	+ 0'.51	− 1'.08
2 "	+ 0.33	+ 0.52	+ 0.09	+ 0.45	− 0.70
3 "	+ 0.42	+ 0.71	+ 0.06	+ 0.41	− 0.46
4 "	+ 0.74	+ 1.12	+ 0.04	+ 0.34	− 0.39
5 "	+ 0.99	+ 1.93	+ 0.12	+ 0.19	− 0.67
6 "	+ 1.73	+ 2.98	+ 0.44	+ 0.05	− 1.07
7 "	+ 2.63	+ 3.99	+ 0.08	− 0.57	− 1.98
8 "	+ 3.15	+ 4.44	− 0.83	− 1.87	− 2.95
9 "	+ 2.87	+ 3.63	− 1.13	− 2.72	− 3.52
10 "	+ 1.32	+ 1.24	− 0.75	− 2.47	− 2.82
11 "	− 0.87	− 1.69	+ 0.18	− 1.41	− 0.97
Noon	− 2.73	− 4.02	+ 0.76	− 0.01	+ 1.45
1 P.M.	− 3.86	− 5.07	+ 0.69	+ 0.90	+ 3.64
2 "	− 3.83	− 4.87	+ 0.40	+ 1.33	+ 4.66
3 "	− 3.07	− 3.83	+ 0.04	+ 1.17	+ 4.56
4 "	− 1.90	− 2.48	− 0.36	+ 0.63	+ 3.54
5 "	− 0.93	− 1.29	− 0.55	+ 0.20	+ 2.20
6 "	− 0.30	− 0.46	− 0.38	+ 0.17	+ 1.20
7 "	+ 0.09	− 0.12	− 0.07	+ 0.36	+ 0.48
8 "	+ 0.40	+ 0.18	+ 0.07	+ 0.45	− 0.24
9 "	+ 0.69	+ 0.52	+ 0.19	+ 0.49	− 0.81
10 "	+ 0.74	+ 0.70	+ 0.28	+ 0.48	− 1.28
11 "	+ 0.70	+ 0.71	+ 0.28	+ 0.47	− 1.52
Midnight	+ 0.58	+ 0.63	+ 0.24	+ 0.48	− 1.38

course of the needle at *Washington*, and Fig. 164 presents it in another way; consider both these Figures together: *TO* is the true meridian, and *MO* the mean position of the magnetic meridian for the year, so that *MOT* is the Variation; at 8 a.m., the needle was at *AO*, the eastern limit of its excursion from the mean position *MO*; then it turned westward, and moving in that direction, attained the limit *BO* at 1 p.m.; here it turned east and advanced to *CO* at 10 p.m.; again it

FIG. 163.

DIURNAL FLUCTUATION OF THE VARIATION AT WASHINGTON, D.C.



turned west but proceeded only to *DO* at 1 a.m., whence it made a final turn to the east—to trace a similar path on the next day and every succeeding day. And this daily journey is typical of what occurs in every part of the world, only that in southern regions the converse of the movement takes place at the same hour. Along some line, therefore, dividing the two magnetic conditions of the globe, there must cease to be

DIURNAL FLUCTUATION [illegible]

Hours.	Name of place, [illegible] of the mean [illegible] the north e[illegible] and minus sign. Washington, D. C.
1 A.M.	+ 0'.[illegible]
2 "	+ 0.[illegible]
3 "	+ 0.[illegible]
4 "	[illegible]
5 "	[illegible]
6 "	[illegible]
7 "	[illegible]
8 "	[illegible]
9 "	[illegible]
10 "	[illegible]
11 "	[illegible]
Noon	
1 P.M.	
2 "	
3 "	
4 "	
5 "	
6 "	
7 "	
8 "	
9 "	
10 "	
11 "	
Midnight	

course o[illegible] in anoth[illegible] the tru[illegible] netic m[illegible] 8 a.m., [illegible] from [illegible] movi[illegible] here[illegible]

Franklin Bay (latitude 82° N.), 1° 6′; again, at Washington the mean range of summer is 9′.3, and only 5′.5 in winter.

The diurnal range at different places and seasons—the oppositeness of movement of the north end of the needle at the same hour in both hemispheres—and the varying hours at which the maxima and minima deflections from the mean position occur, are all illustrated in Fig. 161.

103. The Lunar Change in the Variation.—The *lunar* change of the Variation is a regular ebb and flow, as it were, of the ethereal atmosphere—two maxima and two minima in every lunar day—just like the tides of ocean; the range is small, seldom exceeding 30″ of arc.

104. Magnetic disturbances.—Superposed upon all the foregoing periodic changes are *disturbances*, which occur at any time and in varied degree, modifying their regularity and normal flow, and giving them the semblance of humps, hollows, and sudden breaks without law or order: but by regarding all violent jumps of the needle above a certain value as *disturbances*, and removing them from the observations, the characteristic features of every periodic change stand forth as smooth and regular as those of any other of nature's phenomena. When classified, even the disturbances exhibit periodicity—daily, yearly, and secular: in extent they may be a few minutes of arc, or reach several degrees, and their influence may be restricted to the confines of a small region, or spread simultaneously over the greater part of the globe.

Section Three: The Dip—its Discovery and Fluctuations.

105. Discovery.—In the year 1269, Pierre de Maricourt, a monk, known generally in literature as Peter Peregrinus—a most eminent and learned man—wrote a letter setting forth his magnetical researches. Among these he established the principal facts of the science: that a magnet had two poles

any hour ... were reversible
been foun ... many simi-
The ... determined
mean po ... around every
... [along
... level only
... approach-
... Dip.
... mathematician
... this in
... north and
... have said.
... dem-
... about the
... exactly
... inclines
... Now
... magnet, the
... down-
... intellectual
... the
... Norman.
... first ac-
... honestly
... own ac-

... using
... needle.
... with
... woulde
... quan-
... which was
... small piece of
... Which
... without anie

great regard thereunto, as ignorant of anie such propertie in the stone, and not before having heard nor read of anie such matter, it chaunced at length that there came to my hands an instrument to be made with a needle of sixe inches long, which needle after I had pollished, cut of a just length, and made it stand levell upon the pin, so that nothing rested but onlie the touching it with the stone, when I had touched the same, presentlie the North part thereof declined down in such sort that being constrained to cut awaie some of that part to make it equalle againe, in the end I cut it too short, and so spoiled the needle wherein I had taken so much paines. Hereby being stroken into some cholar, I applied myself to seeke further into this effect, and making certaine learned and expert men, my friends, acquainted in this matter, they advised me to frame some instrument to make some exact triall how much the needle touched with the stone would decline, or what greater angle it would make with the plaine of the horizon."

106. The Secular Change in the Dip.—Since the movement in space of a freely suspended needle is, for convenience, represented by that in two planes—the horizontal and the vertical—or by Variation and Dip; and since one of these components is subject to a variety of periodic fluctuations, it would be natural to infer that the other (inseparably bound to it) should partake of the same changes, and such is the fact, established by observation: the Dip is characterized by secular, annual, and diurnal fluctuations, but the amount is much less than in the Variation. Tables 7, 9, 11, 15, and 16 illustrate the *secular* change at diverse places; consider first the one covered by the longest period of observation—London: in 1576, the Dip was tending toward a maximum, which it reached about 1723; ever since it has been decreasing, with a change of 7° 27′ in 177 years, or an average of 2′.5 a year. At the Cape of Good Hope, the change—a continued increase—was 14° in 129 years, nearly 7′ a year. At Cam-

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that subdiv[illegible]
lar ones that [illegible]
by the weig[illegible]
magnet in w[illegible]
lines of for[illegible]
about the m[illegible]
ing either [illegible]

In 154[illegible]
of Prussi[illegible]
the mag[illegible]
turn to [illegible]
but [illegible]
ous [illegible]
leng[illegible]

[illegible]

[illegible]NDON, ENGLAND.

Year.	Dip.
1882	67° 41′ N.
1885	67 37 N.
1886	67 37 N.
1887	67 30 N.
1890	67 33 N.
1891	67 31 N.
1892	67 29 N.
1893	67 20 N.
1894	67 20 N.
1895	67 24 N.
1896	67 22 N.
1897	67 20 N.

[illegible] THE CAPE OF GOOD [illegible]

[illegible]	Dip.
[illegible]	[illegible] S.
[illegible]	[illegible] S.
[illegible]	[illegible] S.
[illegible]	[illegible] S.
[illegible]	[illegible] S.
[illegible]	[illegible] S.
[illegible]	[illegible] S.

[illegible]

URNAL FLUCTUATION OF THE DIP AND HORIZONTAL INTENSITY AT THE U. S. MAGNETIC OBSERVATORY (OLD SITE), IN WASHINGTON, D. C., FOR THE YEAR 1890.

Hours.	Table 17.	Table 20.
	Mean Hourly Values for the Year.	
	Dip.	Horizontal Intensity, C.G.S. Units.
1 A.M.	71° 04′ 24″	0.198626
2 "	04 22	629
3 "	04 21	632
4 "	04 19	641
5 "	04 17	651
6 "	04 15 *Min.*	658 *Max.*
7 "	04 21	644
8 "	04 40	587
9 "	05 04	511
10 "	05 15 *Max.*	463
11 "	05 13	454 *Min.*
Noon	05 00	488
1 P.M.	04 37	558
2 "	04 21	616
3 "	04 17	646
4 "	04 15 *Min.*	658 *Max.*
5 "	04 19	653
6 "	04 24	637
7 "	04 28 *Max*	623
8 "	04 27	623 *Min.*
9 "	04 27	624
10 "	04 26	626
11 "	04 25	627
Midnight	04 25	0.198624
Mean for the year	71° 04′ 31″	0.198604

ıount of annual change, and the probable completion of a :le, all vary with locality.

107. The Annual and Diurnal Changes in the Dip.—An *ıual* change, which appears in the mean of summer being :ater than that of winter, has also been found by obser- ion.

The *diurnal* change in the Dip at Washington for 1890 is ·en in Table 17, illustrated by Fig. 165: the figures oppo- : *each hour* represent the mean of observations on every ; of the year.

Table 15.

:CULAR CHANGE IN THE DIP AT LONDON,

ear.	Dip.	Year.	Dip.	Year.
:576	71° 50′ N.	1863	68° 12′ N.	1882
1600	72 00 N.	1864	68 09 N.	1885
1676	73 30 N.	1865	68 08 N.	1886
1723	74 42 N.	1866	68 05 N.	1887
1773	72 19 N.	1867	68 03 N.	1890
1786	72 09 N.	1868	68 02 N.	1891
1801	70 36 N.	1869	68 00 N.	1892
1821	70 03 N.	1870	68 00 N.	1893
1830	69 38 N.	1871	67 56 N.	1894
1838	69 17 N.	1872	67 54 N.	1895
1854	68 31 N.	1873	67 51 N.	1896
1860	68 19 N.	1874	67 50 N.	1897

Table 16.

SECULAR CHANGE IN THE DIP AT THE C.
HOPE, SOUTH AFRICA.

Year.	Dip.	Year.	Dip.	Yea
1751	43° 00′ S.	1839	53° 06′ S.	1
1770	44 24 S.	1841	53 09 S.	1
1774	44 30 S.	1842	53 15 S.	
1775	45 18 S.	1843	53 20 S.	
1780	46 48 S.	1844	53 29 S.	
1792	47 24 S.	1845	53 29 S.	
1818	50 36 S.	1846	53 32 S.	
1836	52 24 S.	1847	53 40 S.	

bridge (see Table 7), in 1780, the Dip tained a maximum in 1850—then decrea to this day, the change being 4° 43′ in ; At Acapulco (Table 9) the change has 2′.4 a year. At Washington (Table 11) moving toward a maximum—reache ever since been decreasing, with a cl years, or 1′.7 a year.

Thus it will be seen that the d

receive attention and systematic observation; and because of crude experiments made over a moderate extent of territory showing no change in it, the intensity was at first considered to have the same value in all parts of the Earth.

But Borda reasoned otherwise, although his own experiments covering an area that embraced Brest and Teneriffe, yielded no strong evidence to change the prevailing opinion.

In 1785, Captain de la Perouse of the French Navy, sailed from Brest with two frigates on a voyage of exploration and scientific research.

At the instance of Borda, the French Academy of Sciences prepared instructions for this expedition for determining by systematic observation of the oscillations of a vertical needle, both afloat and ashore, the intensity of the Earth's magnetism.

Paul de Lamanon, a member of the expedition, carried out the instructions; and, as appears by a letter from him read before the French Academy in 1787, found that the total intensity was less in the tropics than toward the poles.

The two ships with all on board were lost—when, or where, has never been ascertained: the last letters from Captain de la Perouse were dated in 1788 from Botany Bay. To Borda through scientific induction and to Lamanon through actual observation are due the first knowledge of the variability of magnetic intensity with locality; but to Humboldt is due its incorporation in science as a physical law, from his extensive experiments in various parts of the world from 1798 to 1804.

Humboldt measured the total intensity, and his method was to estimate it in the number of oscillations that the same needle made in a specific time at different places: thus at Paris the needle made 245 oscillations in ten minutes, at Micuipampa in Peru, 211; and at Lima, 219. The station near Micuipampa was in lat. 7° 2′ S. and long. 78° 48′ W. from Greenwich, at an elevation on the Andes, and where his

needle had no dip—on the magnetic equator, in fact. Proceeding either north or south from this, the needle dipped in opposite directions and the number of its oscillations increased: hence he concluded that the line of least intensity coincided with the line of no dip, and he arbitrarily assigned to the intensity of Micuipampa the value *unity*. This is the origin of Humboldt's standard, which, however, is chiefly of historic interest now, as it and all other relative standards are disappearing in favor of the absolute measure in *dynes*.

It has been shown on Chart I, and explained in Art. 94, how the *total* intensity increases from Equator to Pole, while the converse is true of the *horizontal* component as shown on Chart IV—that it decreases in proceeding over the same ground, that is, from Equator to Pole.

Observations subsequent to Humboldt's have proven that the line of no-dip is neither a line of *least*, nor of *equal*, intensity. Both the line of no-dip and that of least intensity gird the globe as undulating curves in equatorial regions: throughout the circuit of the former a freely suspended needle will assume a horizontal direction—on the latter the magnetic force has everywhere the same value; each line may be surrounded by a system of parallels of more or less regular contour, the one of equal dip, the other of equal intensity, both increasing in value as we proceed toward the Poles, until the first encloses an area where the needle stands vertical and the second a region of greatest intensity.

109. The Horizontal Component especially important.—Where the values of the lines of equal total intensity are resolved into two components—horizontal and vertical—and the former are delineated upon a plane, we have the system of lines of equal horizontal intensity given on Chart IV. This is the most important system, because it represents for every part of the Earth the value of the force that gives direction to compass-needles, as well as the factor that enters into many electrical calculations. Both the whole value of the

horizontal intensity and its variability with time and place are very small quantities, and can be determined accurately only with the most delicate instruments and every refinement of observation and correction.

The loss of magnetism in the magnet used and the inaccuracies due to changes of temperature are the most fruitful sources of error, and from the want of appreciation of these in early observations, as well as imperfection of instruments, the older records of intensity are far less trustworthy than recent ones. Of course the same may be said of all physical phenomena, but it is especially true of magnetic intensity; and it will be better appreciated when it is stated that a dyne itself is a small measure, and yet the daily *variability* of the horizontal intensity occurs only in the fourth figure of the decimal fraction of a dyne that represents the horizontal intensity.

110. The various changes in the Intensity—all small.— —In Tables 18 and 19 are given the *horizontal* intensity at New York and Washington from the earliest epochs of its observation to the present time: the period covered is not yet long enough to infer any *secular* change, or whether there is a cycle of recurrent values; and the same is true of all other

TABLE 18.

SECULAR CHANGE IN THE HORIZONTAL INTENSITY AT NEW YORK.

Year.	Horizontal Intensity, in C.G.S. Units.	Year.	Horizontal Intensity, in C.G.S. Units.
1822	0.1836	1855	0.1816
1835	0.1832	1860	0.1868
1839	0.1850	1872	0.1836
1841	0.1854	1885	0.1862
1842	0.1858	1890	0.1870
1844	0.1848	1895	0.1894
1846	0.1848		

TABLE 19.

SECULAR CHANGE IN THE HORIZONTAL INTENSITY AT WASHINGTON, D. C.

Year.	Horizontal Intensity, C.G.S. Units.	Year.	Horizontal Intensity, C.G.S. Units.	Year.	Horizontal Intensity, C.G.S. Units.
1842	0.1990	1868	0.1998	1882	0.2012
1843	0.1972	1869	0.2004	1883	0.2016
1844	0.1986	1870	0.2007	1884	0.2022
1845	0.1953	1871	0.2008	1885	0.2027
1852	0.1967	1872	0.2010	1886	0.2030
1855	0.2000	1873	0.2003	1887	0.2019
1856	0.1986	1874	0.2005	1888	0.2006
1858	0.1962	1875	0.2007	1889	0.2007
1859	0.1986	1876	0.2009	1890	0.2006
1860	0.1991	1877	0.2015	1891	0.2004
1862	0.1991	1878	0.2014	1892	0.2005
1863	0.1980	1879	0.2015	1893	0.2022
1866	0.1983	1880	0.2018	1895	0.2011
1867	0.1992	1881	0.2020		

parts of the Earth where the intensity has been observed. It may be remarked, however, that at Washington there was a general upward tendency from 1845 to 1886, and since then a vacillating unsteadiness about a mean value.

At New York, no regularity whatever is discernible: the figures strike indiscriminately around a central one.

That there is an *annual* fluctuation of the *total* intensity has been well established by extended and careful observations at three widely separated stations—Toronto, Kew, and the Cape of Good Hope: its value is greatest during the winter months, and least during the summer, the maxima and minima occurring at the solstices.

The *diurnal* fluctuations of the *horizontal* intensity is another well-established fact: Table 20, illustrated by Fig. 166, shows it at Washington for the year 1890. The record was a continuous photographic curve, converted into absolute measure (dynes) by direct observation with a magnetometer at frequent intervals: the value opposite each hour of Table

20 represents the mean of observations on every day of the year; from the mean of three such years—1889, '90, '91—the following is the daily fluctuation of the horizontal intensity at Washington: at 1 a.m. the value was 0.198640 dyne; then it increased to the first maximum, 0.198678, at 6 a.m.; next decreased to the first minimum, 0.198444, at 10.45 a.m.; then increased to the second maximum, 0.198675, at 4 p.m.; and finally decreased to the second minimum, 0.198630, at 8 p.m., whence it increased to pass through a similar cycle on the following day. And such is the fluctuation (with variability due to season, locality, and disturbance) in all parts of the world—frequently masked and often much interrupted within the tropics, but fairly periodic in temperate zones.

Disturbances—sudden and abnormal—break in upon the intensity, and they, too, are periodic.

CHAPTER VIII.

INSTRUMENTS AND METHODS USED FOR DETERMINING THE MAGNETIC ELEMENTS.

Section One: To Determine the Variation at Sea and on Shore.

111. The Variation from swinging ship.—At sea, the Variation can be best determined by time-azimuths of the Sun, observed with an azimuth circle and standard compass, while steaming successively on thirty-two equidistant points. Form [I], supplied to the Naval Service, was devised to facilitate the computation.

Favorable conditions should be chosen for the work—a smooth sea, little wind, and a clear Sun; and the observations should be commenced at the lowest altitude that will allow completing the series before sunset, or if in the morning, as soon after sunrise as practicable.

First, make two rapid and complete circles—one with each helm—to shake out any temporary magnetism that may have lodged in the ship while lying or steering in one direction for some time previous to the operation.

During the observations, the change of course should be made slowly, with a rest of about four minutes on each point, the observation to be taken toward the end of each period, when the magnetic action has had time to produce its effect.

The Sun's bearing by compass should be closely watched while the ship is steady on each point, so that the observer may be well satisfied of its actual bearing when he gives the word "mark!" to the assistant noting time.

Should circumstances endanger getting observations on thirty-two points, then observe on sixteen, or eight, with full time on each.

Form [I] is so complete for the purpose that it is superfluous to treat the subject more at length.

An analysis of the resulting Deviations in column 9 of the Form, gives the "constant A"—to be subtracted from the Variation obtained in column 8; and the remaining value is then probably the most reliable Variation that can be had from observations at sea.

112. The Variation from observations ashore with Compass and Azimuth Circle.—Both the U. S. Navy Compass and the Azimuth Circle are in reality very accurate instruments, and although not of the refinement of the unifilar magnetometer, still such close approximation to exact work is attainable with them, that no opportunity to do it should be omitted.

The compass, circle, tripod, and hack chronometer are to be taken ashore and a spot found where no disturbing matter lies hidden: this may be ascertained by two sets of reciprocal bearings on lines at right angles to each other, the compass and a staff being set up successively at the ends of each line, not more than a hundred feet apart. If the direct and reverse bearings differ by 180°, the spot may be considered desirable; otherwise not.

In such a spot take two series of time azimuths—one in the early morning and the other late in the afternoon when the Sun has about the same altitude—and the mean Variation from both sets should be very accurate.

113. The Gambey Variation Magnet.—This instrument is used on shore: it consists essentially of a magnet suspended horizontally by a fiber of silk, a graduated circle, and a telescope which may be arranged for observing either the magnet or a celestial body.

In Fig. 167, the magnet—a thin bar—hangs in the box

H by a fiber pendant, within a glass tube, from a torsion circle; each end of the magnet is fitted with cross-wires, shown apart at *A*; they may be observed through openings at *M*.

The telescope *T* has motion in a vertical plane; it is made for observation either of a distant object or one close-to, by combining two lenses of different aperture and focal length, and employing shades for excluding the rays that would otherwise fall on the lens in use at the time. A second tele-

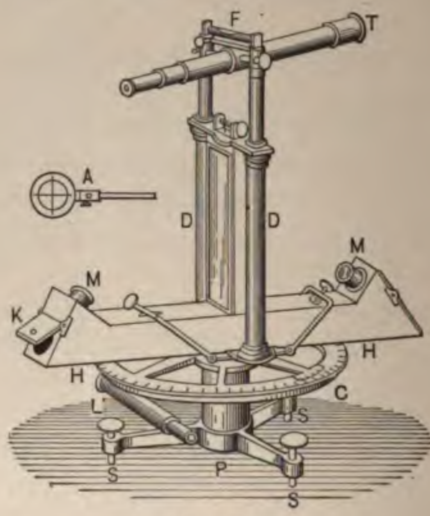


Fig. 167.

scope *L* is attached to the circle *C* and is kept pointed to a distant mark while observing with *T*. The middle part of the magnet is surrounded by a copper tube so that the magnet may be turned round its own axis in this as a stirrup, doors being provided in the box to admit the hand for this purpose. The box is removable in halves so that the magnet may be replaced by a copper weight to allow the fiber to undo any twist in it. Two verniers with tangent screws are fitted to the circle *C*. At *F* there is a riding level.

The box, vernier-arm, and pillars supporting the tele-

scope T—all move in one, on a plate, round the central stem P of the instrument.

The *adjustments* are: 1st, leveling the horizontal circle; 2d, determining the collimation error of the telescope; to do this, it is arranged for observing a near object—a line of the circle—and this is observed with the telescope direct and reversed on its Y's; 3d, ascertaining whether the line of collimation passes through the vertical axis of the system, by pointing the telescope at any line of the circle, and then revolving it in a vertical plane round the horizontal axle so as to observe the reading on the opposite half of the circle; both readings should differ by 180°; if not, the telescope must be shifted laterally by means of a screw for that purpose; the line of collimation is the axis of the telescope, passing through the center of the object glass and the center of the cross-wires in the focus; 4th, freeing the fiber of twist by hanging the copper weight from it for some time while the box is turned in the magnetic meridian.

To make the *observations:* direct both telescopes T and L upon a *distant* mark, and read the verniers; reverse the telescope T in its Y's and repeat this; take the mean of all readings. Leave L set upon the mark, and turn T toward the Sun; clamp all parts; note by chronometer the time of transit of each limb of the Sun across the central wire of T, and read the verniers: this affords data for finding the reading of the *true* meridian on the horizontal circle—see Art. 139, where the problem is explained. Leaving L still set upon the mark, turn the system carrying T until this telescope (now arranged for observing a *near* object) is in the magnetic meridian, and direct it to the north-end of the magnet; when the cross-wires of both telescope and magnet coincide, read the verniers and note the time; reverse the telescope in the Y's and repeat this; take the mean of the readings. Direct the telescope to the south-end of the magnet and make a similar series of observations. Now turn the magnet round its own

axis until the under side becomes the top, and repeat the preceding observations on each end of the magnet. The mean of the four sets of readings will give the Variation when compared with the reading of the circle corresponding to the true meridian; and to be sure that the circle has not moved during the observations, the telescope *T* should be finally directed to the distant object, and the reading of the verniers compared with what it was at first. About 10 a.m. is the best time to make an observation, as the magnet then occupies more nearly its mean position for the day.

Section Two: To Determine the Dip and Total Intensity with Barrow's Circle on Shore.

114. The instrument described.— Fig. 168 represents it, arranged for Dip. It consists of a wooden box *B*, with a ground-glass back—hinged, so as to open, and a clear pane of glass in front—immovable; facing this, two pillars *P* support a fixed vertical circle *C*; against this, cross-arms *A* turn on the horizontal axis *H*, carrying the tangent screw *T*, verniers V, lenses *L*, for reading them, and microscopes *M*, with cross-wires in focus of each, for observing the ends of the dipping-needle; *E* is a level fixed on the box: this whole system revolves, in one, round the vertical stem *D*; to this stem are firmly attached the foot-screws *F* and the horizontal circle *K*, provided with vernier and clamp (not visible). Within the box *B* there is a needle *ns*, having an axle through its center of gravity, which rests on two agate knife-edges: *Q* is a screw, which, turned forward, causes two forks to rise under the axle and lift the needle from its agate rails; reversed, it lets the axle down again and centers it in the circle *C*.

The needle has free motion in the vertical plane *only*, and when this plane coincides with the magnetic meridian, the

needle points in the direction of the total intensity at the angle of the Dip.

Note: The 0° of circle C is erroneously placed: it should be in the horizontal diameter, and 90° in the vertical.

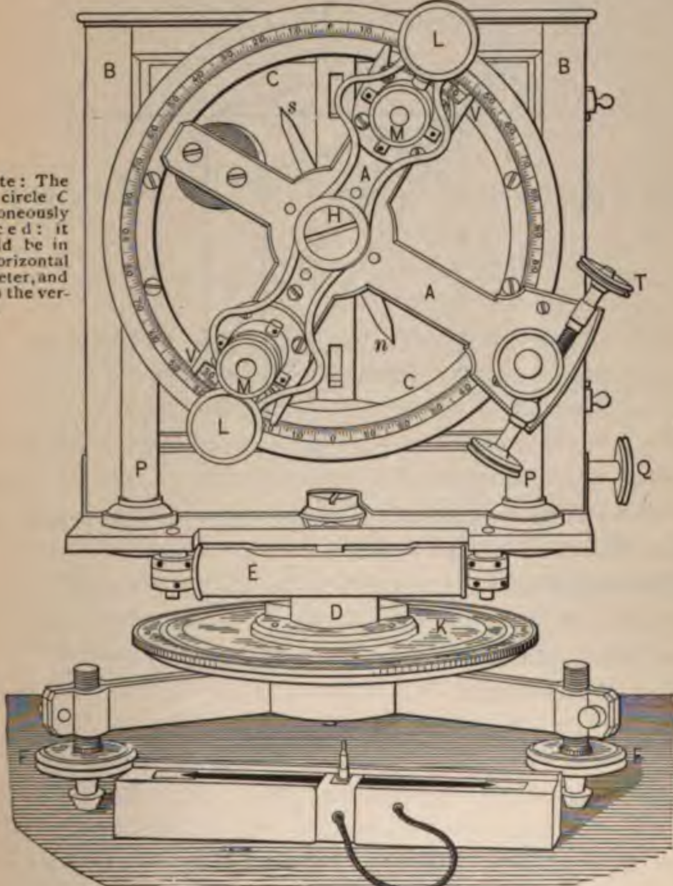


FIG. 168.

115. Formulæ for determining the Dip.—Consider Fig. 169 as representing the needle *ns* on its agate supports in the vertical plane of the magnetic meridian; let $OE = T$, represent the direction and amount of the Total Intensity; then

$OCBy$ being the horizontal plane, the components of T in this and in the vertical plane respectively, are $OB = H$, and $BE = Z$; $BOE = D$, is the Dip.

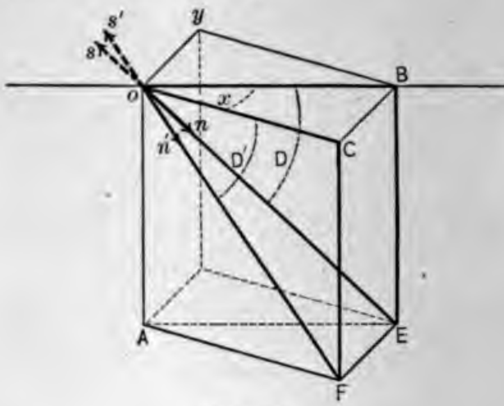


FIG. 169.

The vertical component Z is the same in every azimuth, that is, $BE = CF = OA = Z$.

Then by Trig.

$$\sin D = \frac{Z}{T}, \quad \therefore\; Z = T \,.\, \sin D, \quad . \quad . \quad . \quad (1)$$

$$\cos D = \frac{H}{T}, \quad \therefore\; H = T \,.\, \cos D, \quad . \quad . \quad . \quad (2)$$

$$\cot D = \frac{H}{Z} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now let the box containing the needle be turned round its vertical axis by any amount, say the angle $BOC = x$, until the needle takes the direction $n's'$ in a new dip, D'; then the trace of this direction on the horizontal plane will be OC. Resolving H ($= OB$) into this trace and perpendicular to it, we have OC and CB, latter equal to Oy; or by trigonometry,

$$\cos x = \frac{OC}{OB} = \frac{OC}{H}, \quad \therefore \; OC = H \, . \cos x, \quad . \quad (4)$$

$$\sin x = \frac{CB}{OB} = \frac{CB}{H}, \quad \therefore \; CB = H \, . \sin x, \quad . \quad (5)$$

$$\cot COF = \cot D' = \frac{OC}{CF} = \frac{H \, . \cos x}{Z}, \quad . \quad . \quad . \quad (6)$$

from (4), and since $CF = Z$; then by means of (3), equation (6) becomes

$$\cot D' = \cot D \, . \cos x. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

The component Oy being perpendicular to the vertical plane through the needle, is parallel to its axle—tending to slide it laterally on the agate bearings, and hence is neutralized; only OC, or H, $\cos x$, see eq. (4), has any effect in giving motion to the needle toward the horizontal plane; it has a maximum value when the needle is in the vertical plane of the magnetic meridian, and steadily decreases as the needle departs from that plane until it arrives in one perpendicular to the meridian, when the value becomes zero; with this motion of the needle in azimuth corresponds an increase in the Dip until the needle stands vertical at the instant the plane through it makes an angle of 90° with the meridian: this, moreover, is evident, since no part of the horizontal component then remains to pull the needle out of the vertical.

By reference to the trigonometrical formulæ in Part Sixth, it will be seen that these facts are deducible from equation (7) . . . $\cot D' = \cot D \, . \operatorname{cox} x$; for if $x = 0$, then $\cos 0° = 1$, and $\cot D' = \cot D$, whence $D' = D$, or the needle indicates the natural Dip of the place; and if $x = 90°$, then $\cos 90° = 0$, and $\cot D' = 0$, whence $D' = 90°$, or the needle stands vertical.

Now let the needle be turned successively in azimuth to *any* two positions *such* that the vertical planes through them

make with *each other* an angle of 90°: this is represented in Fig. 170, where OB is the magnetic meridian, and OC and

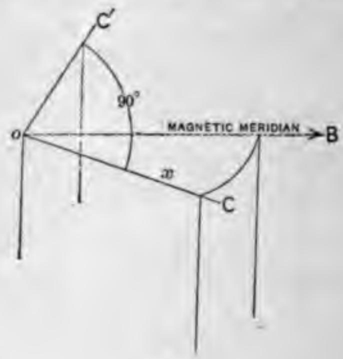


FIG. 170.

OC' are the traces on the horizontal plane of the vertical planes through the two positions of the needle. $COC' = 90°$; $BOC = x$; $BOC' = 90° - x$.

Let D' be the Dip in position OC, and D'' in OC': then by eq. (7) for the two positions, we have

$$\cot D' = \cot D \,.\, \cos x, \quad \ldots\ldots\ldots \quad (7)$$

$$\cot D'' = \cot D \,.\, \cos (90° - x) = \cot D \,.\, \sin x. \quad . \quad (8)$$

Squaring (7) and (8) and adding them, we have

$$\cot^2 D' + \cot^2 D'' = \cot^2 D(\cos^2 x + \sin^2 x) = \cot^2 D, \quad . \quad (9)$$

which, since D is the Dip in the meridian, or that proper to the locality, affords a means of determining it from observations of the Dip D' and D'' in *any* two azimuths *out* of the magnetic meridian, provided they form a right angle with *each other*.

116. Means of correcting errors due to defects of the instrument.—However carefully a dip circle may be made, still it is liable to have certain small defects; the mode of cor-

recting errors due to these, as well as the essentials of a *perfect* instrument, will now be stated, reference being made to Fig. 168; by "*face*" of the instrument is meant the graduated surface of the circle C.

1st. The zero-line (0°) of the vertical circle *C* should be horizontal: if not, two observations—first with face east and then west—will afford readings whose mean will be free from this error. (In Fig. 168 the 0° is erroneously placed.)

2d. The axle of the needle should be in the center of the circle *C*, and the screw *Q* for raising and lowering it, centers it by this action; but if not, the mean of the readings of both ends of the needle will correct for any eccentricity.

3d. The magnetic axis should coincide with the axis of figure of the needle: if it does not, take the mean of two readings—one with the marked side of the needle toward the observer and the other with the *un*marked side toward him, having turned the needle over. Four needles are furnished, each numbered and poles marked on one face, for conveniently referring to them.

4th. The upper surface of the agate rails should be horizontal: if not, the needle will tend to roll down them, and the error thus induced, will be eliminated by taking the mean of two observations, with the face of the instrument first east and then west.

5th. The axle should pierce the exact center of gravity of the needle: otherwise, the preponderating weight of steel will assist or oppose magnetic attraction according to the side of the axle on which it exists, and an observation would be due to gravity and magnetism combined, rather than to the latter alone. To eliminate the error, the poles of the needle must be reversed by magnetizing it with steel bars provided for that purpose: then it is evident that if greater weight were in the upper half of the needle before reversal, it will be in the lower half after; in the former case it opposes magnetic attraction and in the latter aids it to the same ex-

tent, so that the mean of two readings, with poles direct and reversed, will give the correct value.

117. To reverse the magnetism of the needle.—Place it flat on the block supplied for that purpose, north end to the operator's right and marked face uppermost, and secure it with the brass clasp. Take a bar in each hand—that in the right with its north pole downward and that in the left with its south pole downward—and bring both lower poles close to the axle, inclining the bars at an angle of about 80° with the needle. Usually, there are ledges on the block for guiding the bars parallel to the geometrical axis of the needle, and the needle is slightly sunk below the surface of the block, to prevent contact of the bars with it in rubbing, which might injure it: draw both bars slowly and steadily outward to the ends of the needle and beyond them a few inches—raise them a foot above the block—bring them back to the axle, and draw them out again. Do this ten times. Then turn the needle over so as to have its unmarked side uppermost, and make ten passes with the bars as before. The ends that were at first north and south poles, are now south and north poles respectively. A weak needle will indicate the same Dip that a strong one will; but to overcome friction of the axle and bearings, as well as small impediments of dust, the needle should be strong rather than weak. When not in use, the bars should be placed side by side, unlike poles together, and well distant from the instrument while observing.

118. To find the reading of the magnetic meridian on the horizontal circle.—The instrument must first be levelled: for this, turn the system carrying the level E so that the latter shall come successively over two foot-screws and work these until the bubble remains in the middle in every azimuth. Turn the system to face south: now move the cross-arms A until the microscopes M are nearly vertical, when clamp them; set upper vernier of arm on 90° by tangent screw T; turn system containing needle until upper end of needle ap-

proaches wire of microscope, when clamp system to circle K; center needle by means of screw Q; complete exact coincidence of wire and needle-point by tangent screw of circle K, and then read and record the verniers of this circle: set lower vernier on 90°, bring about exact coincidence of lower wire and needle-point by tangent screw on circle K, and then read and record the verniers of this circle as before. Turn the system to face north, and repeat the foregoing observations. The mean of all the readings will be that of a line at right angles to the magnetic meridian; whence, by applying 90° to that mean, a reading is obtained to which the verniers on the horizontal circle must be set and clamped (by turning the moveable system) in order that the needle shall have free motion in the vertical plane of the magnetic meridian.

119. Procedure of observing the Dip.—This is implied in the enumeration of instrumental defects and the means of eliminating errors due to them; but to be explicit, the procedure will be stated here in connection with Table 21: in this, the numbers denote the order of sequence of the observation,

TABLE 21.

Instrument.	Poles Direct.				Poles Reversed.			
	Marked Side of Needle Toward Observer.		*Un*marked Side of Needle Toward Observer.		Marked Side of Needle Toward Observer.		*Un*marked Side of Needle Toward Observer.	
	Upper End.	Lower End.	Upper End.	Lower End.	Upper End.	Lower End.	Upper End.	Lower End.
With face east......	(1)	(1)	(2)	(2)	(8)	(8)	(7)	(7)
With face west.....	(4)	(4)	(3)	(3)	(5)	(5)	(6)	(6)

with the corresponding conditions of instrument and needle at the side and top.

Generally, three readings for each end of the needle will suffice, the screw Q being turned to center the needle between every two: the cross-wires of both microscopes M are

to be successively brought into coincidence with the points of the needle by the tangent screw *T*, and the corresponding vernier *V* read by the lens *L*.

When the instrument is levelled and reading of magnetic meridian determined, proceed as follows: With face east, poles direct, and marked side of needle toward observer, take readings (1), (1), Table 21; then turn the needle over on its supports with the unmarked side toward the observer and take readings (2), (2); next revolve the system containing the needle 180° in azimuth, or face west, and with the unmarked side of the needle still toward the observer, take readings (3), (3); again turn the needle so as to present the marked side to the observer and take readings (4), (4): now place the needle on the wooden block and reverse its poles; return it to the supports with marked side toward the observer and take readings (5), (5); turn it with unmarked side to the observer and take readings (6), (6); revolve system 180° in azimuth, or face east, and with unmarked side of needle still toward observer, take readings (7), (7); finally, turn needle with marked side toward observer and take readings (8), (8). The mean of all the readings will be the Dip of the place free from instrumental errors.

120. To determine the Total Intensity.—The circle is to be arranged for this, as in Fig. 171. Four needles in all are supplied—No. 1 or 2 for observing the Dip, and their poles may be varied in strength or reversed at will without affecting the result; while 3 and 4 are for determining the Intensity, and their magnetism should never be disturbed by increase, diminution, or reversal. All the needles are alike in form, but No. 4 has three small holes near each end along its axis of figure; a small piece of platinum is supplied for insertion in any one of these, and when its weight is accurately known and the exact distance from the center of the hole to the center of the axle is measured, these data afford the means of calculating the effect of gravity on the weight—its mo-

ment—when the needle turns. The weight is always so placed that it opposes terrestrial magnetic attraction—on the upper end of the needle.

Note: The 0° of upright circle should be in the horizontal diameter, and 90° in the vertical.

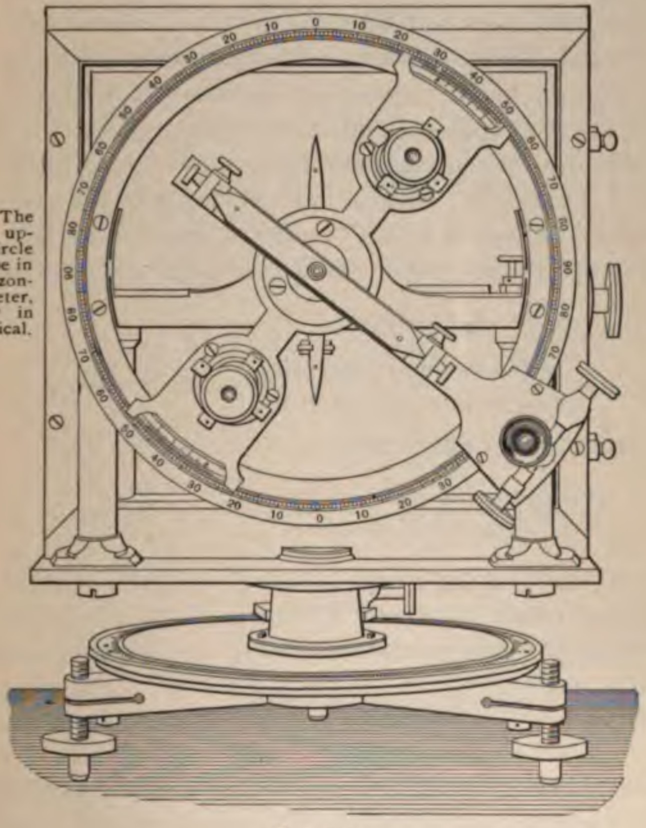


Fig. 171.

121. The principle involved in determining the Intensity.—It may be stated thus: needle No. 3 is placed on the agate rails and the box turned until the needle is free to move in the vertical plane of the magnetic meridian, when it settles into the line of Dip; No. 4 is placed on the cross-arms as shown in Fig. 171, and these are successively turned into two

specific positions, causing in each a deflection of No. 3 from the natural line of Dip. This deflection is a position of equilibrium between the magnetic intensity of the Earth and that of No. 4: it establishes a ratio between these two intensities. No. 3 is now removed from the instrument and well away from it, and No. 4 is placed on the agate rails; but it does not settle into the line of natural dip because of the weight in its upper end; the angle of deflection from the Dip D is therefore the ratio of the magnetic intensity of No. 4 to the moment of the weight. This ratio combined with the preceding gives the value of the Earth's magnetic intensity, as will more clearly appear when put in the following form of equations:

First part of observation:

$$\frac{\text{Earth's magnetic intensity}}{\text{magnetic intensity of No. 4}} = A. \text{ (known)},$$

Second part of observation:

$$\frac{\text{magnetic intensity of No. 4}}{\text{moment of weight}} = B. \text{ (known)}.$$

Whence, multiplying these, member by member, and cancelling the term "Magnetic Intensity of No. 4" common to numerator and denominator, we have

$$\frac{\text{Earth's magnetic intensity}}{\text{moment of weight}} = A \times B,$$

whence Earth's Magnetic Intensity $= T = A \times B \times$ Moment of Weight (all known).

A magnetic needle has two foci of strength—the poles—both equal—one near each end: let m represent the strength of one pole and l the length of the needle; then the product $m.l$, denoted by M, is defined as the magnetic moment of the needle.

122. Formulæ upon which the determination of the Intensity is based.—Fig. 172 shows needle No. 4 on the

agate rails in equilibrium between the acting forces—the weight W, the magnetic moment M of the needle, and the magnetic intensity T of the Earth. Let $\overline{OW} = r$: then by the figure, $BOE = D$; $BON = POW = \phi$; $\overline{OP} = \overline{OW} \,.\, \cos POW = r \,.\, \cos \phi$; and $NOE = BOE - BON = D - \phi$; the needle is deflected from the natural line of the Dip $\overline{OE}$ by the amount of the angle $NOE = D - \phi$.

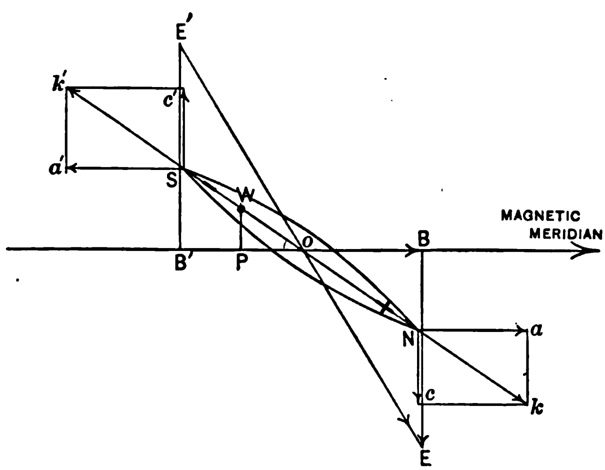


FIG. 172.

Resolving the forces horizontally and vertically, and taking their moments round the center of rotation, we have for the moment of weight $= W \,.\, \overline{OP} = W \,.\, r \,.\, \cos \phi$, acting vertically downward. In regard to the magnetic force, it must be understood that the action between the Earth and the needle is one of mutual attraction at the lower end of the latter, and equal mutual repulsion at the upper end, and that it is appropriately represented by the product of both intensities, each with its proper sign; that is, considering the field of the Earth minus (—), the lower pole of the needle must be plus (+) and the upper minus (—), and we should have for the former $(-T)(+m) = -m \,.\, T$, and for the latter $(-T)(-m) = +m \,.\, T$. In the other magnetic hemisphere, the

field would necessarily be plus, the lower end of the needle minus and the upper plus: all this, however, to make clear the existing conditions.

The force $m \,.\, T$ at each end of the needle may be represented in direction and amount by Nk and Sk' as in Fig. 172, or by two pairs of components, Na and Sa', each equal to $m \,.\, H$, acting horizontally, and Nc and Sc', each equal to $m \,.\, Z$, acting vertically; the arm of the horizontal pair being $\overline{NB} + \overline{SB'}$, and of the vertical pair BB'; in fact, these constitute two couples tending to motion in opposite directions. The moment of a couple is the product of one of the forces into the arm; hence the magnetic moments of these couples are $m \,.\, H\,(\overline{NB} + \overline{SB'})$ and $m \,.\, Z \,.\, \overline{BB'}$, the former conspiring with the weight to rotate the needle into a horizontal position and the latter tending to turn it vertically; when they and the moment of the weight balance, we have,

$$m \,.\, H(\overline{NB} + \overline{SB'}) + W \,.\, r \,.\, \cos\phi = m \,.\, Z \,.\, \overline{BB'}, \quad . \quad (10)$$

or, transposing

$$m \,.\, Z \,.\, \overline{BB'} - m \,.\, H(\overline{NB} + \overline{SB'}) = W \,.\, r \,.\, \cos\phi. \quad . \quad (11)$$

Let $ON = OS = \frac{1}{2}\, l$.

From Fig. 172, by Trig.

$$\cos BON = \frac{OB}{ON}, \quad \therefore \ \overline{OB} = \overline{ON} \,.\, \cos BON = \tfrac{1}{2}l \,.\, \cos\phi,$$

and $\qquad \overline{BB'} = 2\overline{OB}$.

$$\text{Hence} \qquad \overline{BB'} = l \,.\, \cos\phi, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

$$\text{and similarly,} \qquad \overline{NB} + \overline{SB'} = l \,.\, \sin\phi. \quad . \quad . \quad . \quad . \quad . \quad (13)$$

Substituting in (11) the values of (1), (2), (12), and (13), and remembering that $m \,.\, l = M$, Art. 121, we have

$$M \,.\, T \,.\, \sin D \cos\phi - M \,.\, T \,.\, \cos D \sin\phi = W \,.\, r \,.\, \cos\phi, \quad (14)$$

$$\text{or} \quad M \,.\, T \,.\, (\sin D \cos\phi - \cos D \sin\phi) = W \,.\, r \,.\, \cos\phi. \quad (15)$$

This by Trig. (Chauvenet, p. 21) becomes

$$M \,.\, T \,.\, \sin (D - \phi) = W \,.\, r \,.\, \cos \phi, \quad . \quad . \quad (16)$$

whence

$$M \,.\, T = \frac{W \,.\, r \,.\, \cos \phi}{\sin (D - \phi)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

W and r are determined by weighing and measuring, and D and ϕ are observed, and thus the *product* $M \,.\, T$ of the magnetic moment of the needle and the Earth's total intensity becomes known.

As the weight of W depends on the force of gravity, which varies with the latitude, a correction for this will be necessary: let $W' =$ the weight at Lat. 45°, then the weight at any other latitude L will be $W = W' \,(1 - h \,.\, \cos 2\,L)$, h being a constant $= 0.002588$. This is explained in Part Sixth.

The next step is to determine the *ratio* of M to T, for combination with their *product*, in order to eliminate M and get the value of T. Needle No. 4 is removed from the agate rails and No. 3 substituted; the former is fixed on the cross-arm and deflects the latter; when equilibrium results, it is between the magnetic intensity of the Earth and that of No. 4. Let M' denote the magnetic moment of No. 3, and ϕ' its angle of deflection; these quantities are analogous to M and ϕ already used, and the conditions and investigation are the same as with No. 4 on the rails—the interaction of Earth and needle are similar in both cases, while the deflecting *mechanical* moment of the weight in the first case is replaced by the deflecting *magnetic* moment of No. 4 in the second case. Therefore the relation between the Earth and No. 3 may at once be written from the first member of equation (15), or its reduced form (16), that is, $M' \,.\, T \sin (D - \phi')$: this is balanced by the combined magnetic moment of Nos. 3 and 4, which is equal to the product of the moments of the two

needles and a certain other quantity, which call F; that is, $M \,.\, M' \,.\, F$.

This quantity F is a function of the distance between the centers of the needles and of certain integrals dependent on the distribution of magnetism in them: it will be explained in Part Sixth. The equation of equilibrium, then, is

$$M' \,.\, T \sin (D - \phi') = M \,.\, M' \,.\, F, \quad . \quad . \quad . \quad (18)$$

whence

$$T \sin (D - \phi') = M \,.\, F, \quad . \quad . \quad . \quad . \quad . \quad (19)$$

or

$$\frac{T}{M} = \frac{F}{\sin (D - \phi')}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (20)$$

the ratio required in known quantities, for F is obtained by calculation from certain measurements that may be made, and D and ϕ' are observed.

Multiplying equations (17) and (20), member by member, we have

$$M \,.\, T \times \frac{T}{M} = \frac{W \,.\, r \,.\, \cos \phi}{\sin (D - \phi)} \times \frac{F}{\sin (D - \phi')}, \quad . \quad (21)$$

whence

$$T^2 = \frac{F \,.\, W \,.\, r \,.\, \cos \phi}{\sin (D - \phi) \sin (D - \phi')}. \quad . \quad . \quad (22)$$

Extracting square root of both sides,

$$T = \sqrt{\frac{F \,.\, W \,.\, r \,.\, \cos \phi}{\sin (D - \phi) \sin (D - \phi')}}. \quad . \quad (23)$$

This is the value of the *total intensity* in absolute measure—dynes—when weights and distances have been determined in grammes and centimetres, and time in seconds.

Compared with the method to be given hereafter for determining the horizontal component of the intensity, it is

especially accurate in latitudes toward the magnetic poles where the horizontal component becomes less and less and the total intensity increases; but even in equatorial regions it has yielded excellent results.

123. The factor for distribution of magnetism in needle found by experiment.—In equation (23) the quantity F is the only one not directly known, but while it may become so by calculation, it may also be determined by experiment with the dip-circle itself: for this, a brass frame f, Fig. 173,

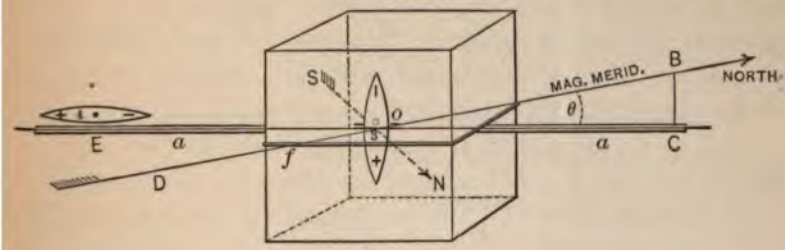


FIG. 173.

with arms, a, is provided to slip over the box containing the needle, until it rests on ledges on a level with the agate rails. With face of instrument east so that needle No. 3 rests in line of natural dip (NS Fig. 173), needle No. 4 is placed at measured distances on each arm—as at E—its axis in the plane in which No. 3 has free motion; this is then deflected to a certain angle by needle No. 4, and the box is turned in azimuth until No. 3 stands vertical; the *vertical* plane through OC then makes a certain angle θ with the magnetic meridian—it is read off on the horizontal circle. The value of the component H in this new direction is,

$$OC = \overline{OB}.\cos BOC = H.\cos\theta. \quad . \quad . \quad . \qquad (24)$$

The vertical position of No. 3 is due to its own magnetic moment in combination with two others, namely, that of the Earth and that of No. 4—tending to turn No. 3 in opposite directions: the equation of equilibrium may therefore be

written directly from the preceding investigation, only that here the value of H becomes $H.\cos\theta$; hence,

$$M'.Z.\cos\phi' - M'.H.\cos\theta.\sin\phi' = M'.M.F. \quad (25)$$

But since No. 3 is vertical, its deflection ϕ' equals 90°, whence $\cos 90° = 0$, and $\sin 90° = 1$, and equation (25) becomes

$$-M'.H.\cos\theta = M'.M.F, \quad . \quad . \quad . \quad (26)$$

or

$$-H\cos\theta = M.F,$$

or

$$F = -\frac{H}{M}.\cos\theta. \quad . \quad . \quad . \quad . \quad . \quad (27)$$

If s denotes the distance between the centers of both needles, it is shown in Part Sixth that

$$M'.M.F = \frac{2.M'.M}{s^3}\left(1 + \frac{p}{s^2} + \frac{q}{s^4} + \text{etc.}\right). \quad . \quad (28)$$

Hence

$$F = \frac{2}{s^3}\left(1 + \frac{p}{s^2} + \frac{q}{s^4} + \text{etc.}\right). \quad . \quad . \quad . \quad . \quad (29)$$

Equating both values of F from (27) and (29), we have

$$-\frac{H}{M}.\cos\theta = \frac{2}{s^3}\left(1 + \frac{p}{s^2} + \frac{q}{s^4} + \text{etc.}\right). \quad (30)$$

The series within parentheses converges rapidly, so that terms beyond the third may be neglected. By observing at different distances, or for various values of s, equations are obtained for determining or eliminating p and q, whence F is obtained from (29) and then T from (23).

The moment of a magnet varies with the temperature, diminishing in almost steady ratio as that increases; therefore if the temperature varies *during the observation for intensity*, a correction must be made, otherwise the value of M in equations (17) and (20) will not be the same and cannot cancel in equation (21).

The temperature correction for No. 4 may be practically determined by placing it in a little trough of water at two temperatures—say, 32° and 132° Fahr.—and observing the deflection it will produce on a delicately suspended needle at each; the difference of the two deflections divided by 100 will give the amount of the correction for each degree from any standard temperature at which the magnetic moment may be determined.

All needles are liable to variation of their magnetism with lapse of time, with shock, ill-usage, the influence of iron masses or powerful magnets: all these, except the first, are avoidable by care, and with respect to the first, the time for intensity observations is so short that the magnetism of the needles may be considered constant during it.

The method of making intensity observations has already been indicated, but it will be explicitly stated here: in Table 21, when the observations for Dip were finished at the stage denoted by (8), (8), the face of the instrument was east; now remove the dip-needle, substitute No. 4 loaded with its little platinum weight, and observe this under the conditions denoted by (1), (1); (2), (2); (3), (3); and (4), (4) of Table 21; from these the value of the deflection ϕ is obtained.

This series ends with the face of the instrument west: now remove No. 4 and substitute No. 3; then fix No. 4 firmly on the cross-arm A as indicated in Fig. 171, north pole downward; turn the arm—No. 4 deflecting No. 3 during the motion—until the ends of No. 3 appear coincident with the cross-wires of their respective microscopes, when read and record the verniers of the vertical circle. Revolve the arm A in the opposite direction until the microscope which was at first uppermost is now below; bring the ends of the needle and cross-wires into coincidence as before, and read and record the verniers of the vertical circle: the readings of the vertical circle in the two positions of the cross-arm afford the data for finding the angle ϕ'.

Section Three: To Determine the Dip and Total Intensity at Sea with Fox's Circle.

124. The Fox Circle described.—This instrument was devised specially for observations at sea, and has been extensively used, yielding very good results even under unfavorable conditions of wind and weather: it is therefore a tried and reliable instrument.

It consists (see Fig. 174) of a frame *F* supporting a circu-

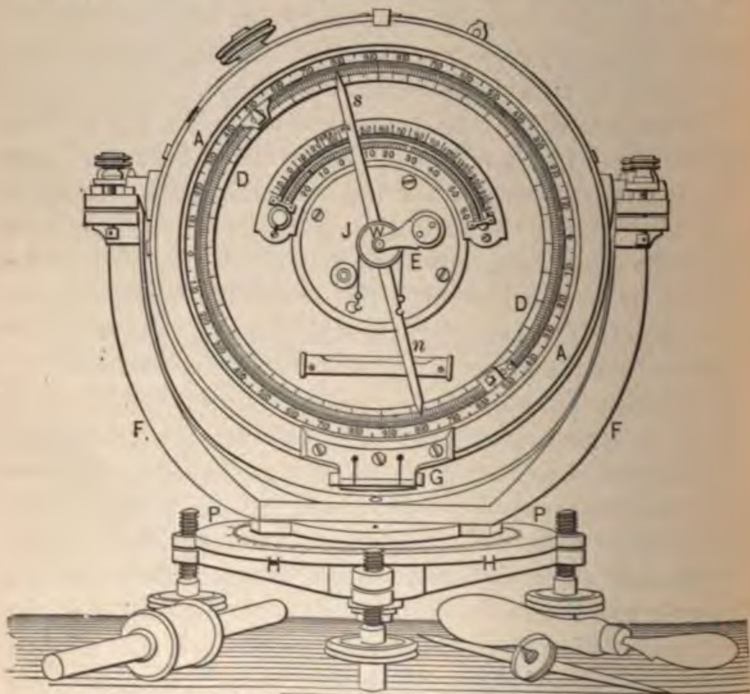


FIG. 174.

lar brass box which has a glass cover hinged at *G*; near the rim of the box are two graduated circles *A* and *D* whose

faces, while being in parallel planes, are yet sunken one below the other, so that the needle *ns* swinging over the graduation of *D* is still below the level of *A*; thus the ends of the needle and the divisions of both circles coincident with them are seen together—a means of avoiding errors of parallax as well as of constituting a vernier; the zero-line (0°) of graduation is horizontal. The bracket *E* has an in-and-out motion (perpendicular to the face of the instrument) by means of a screw at the back—to adjust the needle in its sockets, or release it entirely for removal; its disk *J* may be turned round in a vertical plane.

The axle of the needle is ground down at its ends to delicate conical pivots that work in jeweled sockets—one in the bracket, the other in the brass box, and both in a line perpendicular to the planes of the circles *A* and *D* through their centers; there is a grooved aluminum wheel *W* fixed to the axle; a silken fiber with a minute hook at each end and a series of graduated little weights are supplied for use on the grooved wheel. This whole upper system rests on a plate *P* having motion in azimuth round the center of the horizontal circle *H* which is attached to the frame that bears the footscrews. In use, the instrument is set upon a stout gimbal table that is firmly secured to the deck; this prevents it taking up much of the ship's motion: like the compass, it hangs level.

125. The ship's iron affects observations for Dip and Intensity.—Just as a ship is swung for compass deviations, so must she be to ascertain the effect of her iron on the Dip and Intensity; and the results obtained, constitute tabulated corrections to be applied to all observations. The swinging should be done before sailing, with every great change of geographical position, and on return to the port of departure.

A ship, like every other magnet, has two principal foci of strength, separated by a neutral line; and according to the

location of the poles of the ship with reference to the site of the Fox Circle, they will conspire or conflict with the Earth in its influence on the Dip and Intensity. The gimbal table should be set up as near the neutral line as circumstances will permit, and on the middle fore-and-aft line of the ship; the line of the keel should be drawn on the table, and also a circle, divided to degrees, with its zero (0°) on the keel-line. Now consider Fig. 175: the ship heads north magnetic, the Fox

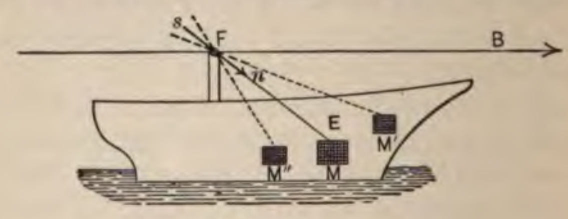


FIG. 175.

Circle is mounted at F, and its needle settles into the line of Dip FE; suppose that M is one of the two centers of magnetic strength of the ship—the one nearest the instrument—that it is a pole of the same name as the Earth's magnetism in the region where the ship is—and located in the line of the Dip.

It merely increases the Earth's intensity, but does not change the Dip. But suppose it at either M' or M''—then it affects both the Dip and Intensity; and if it were a pole of different name from the Earth's magnetism at the place, the effect would be opposite in kind.

All observations for Dip and Intensity must be taken with the needle free to move in the vertical plane of the magnetic meridian; but the ship may head any other course than magnetic north or south: suppose it N.E. as at (2) Fig. 176; the force of the pole M may be resolved vertically and horizontally, and the latter may be further split up into forces parallel and perpendicular to the magnetic meridian. The vertical component does not vary with the course; the component perpendicular

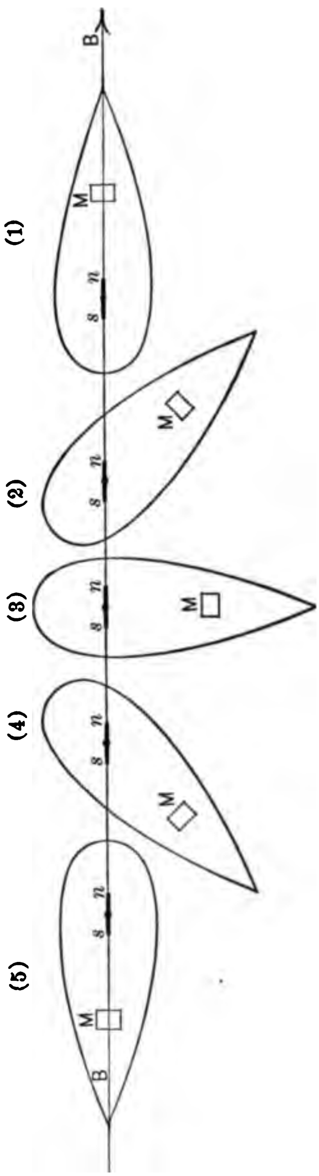


FIG. 176.

to the meridian produces no action at all—it merely works against the sockets of the needle; the force parallel to the meridian tends to deflect the needle, and it varies as the *cosine* of the magnetic course—becoming a maximum when the course is 0°, and a minimum when it is 90°. On southerly courses the effect changes sign.

As the ship swings round the compass, the line joining the Fox Circle and pole *M* describes the surface of a cone whose apex is at the center of the needle; and the force of the pole upon the needle is exerted along this surface in the direction of the line that generates it—making the needle more steadfast in direction in one part of the circuit, and more easy to move in the other: this variabi y of the *ship's* magnetism upon the needle is expressed by the *cosine* of the magnetic course—a maximum, plus or mini s, in the meridian, and zero when the course is 90° E. or W., for then, as in (3) Fig. 176, its pull is at right angles to the axis of the dipping needle. But the poles of the ship may be differently located, and then the variability of the Dip and Intensity with the course would be different; hence the necessity of swinging ship and ascertaining the actual condition and its effects.

Observations with the Fox Circle require both weights and magnets to produce the necessary deflections: with weights, it is the balancing of gravity against the magnetic force of the Earth—both acting on a suspended needle; in the case of other magnets, it is the equilibrium of this same needle under the influence of two magnetic forces—the Earth's and that of another needle. The underlying principle of both conditions has been already explained.

126. To determine the Dip.—Find from the compass course the ship is heading, the corresponding magnetic course: place the instrument on the gimbal table, the zero-line (0°) of the horizontal circle in the keel-line marked on the table, and turn the vertical circle into the magnetic meridian as indicated by the angle of the magnetic course.

Throughout the observations, the ship must be kept very steady on her course, for it is evident that any departure from it turns the dip circle by the same amount from the magnetic meridian and introduces error into the result.

With the instrument leveled and face east, observe and record the division of the outer circle (opposite each end of the needle) that coincides with the corresponding division of the inner circle, turning the bracket to and fro slightly and rubbing the center pin at the back with the ivory disc to agitate the needle while observing it: turn the face west and repeat these observations. Adjust the graduated circle at the back to an angle of 45° from the dip just observed, and screw the deflector into its arm so as to repel the needle; when at rest, read and record both ends as before; revolve the back circle through 90°, or so as to repel the needle in the opposite direction, and read and record both its ends: turn the circle face east and repeat these observations with the deflector in the same relative positions it was with the face west. The mean of all the readings will be the Dip—affected, however, with the error due to the iron of the ship—that is, for the vertical component and for the horizontal component proper to the course she was steering. When this error, taken from the *dip* table obtained by swinging, has been applied, we have the Dip proper to the locality.

127. To determine the Intensity: with weights; with deflectors; with both combined.

FIRST, WITH WEIGHTS: Remove the deflector used in the dip observations, and when the needle—designated by the letter *A*—has settled into the line of dip, place the silken fiber over the groove of the wheel, and attach a weight to one of the hooks; the needle will be deflected—observe and record both its ends; shift the weight to the other hook, and again observe and record both ends. From the mean of the readings in the two positions of the needle we get the deflection

—the ratio of the two forces, mechanical and magnetical, that are in equilibrium.

If this ratio had been determined with the same weight, the same needle, and at the same temperature at a base station, and the magnetism of the needle had not changed in the interval, the values of the intensity at the base and at any other station would be to each other inversely as the *sines* of the angles of deflection, or, denoting these angles by ϕ_1 and ϕ_2, respectively, and the corresponding intensities by T_1 and T_2, we have

$$\frac{T_2}{T_1} = \frac{\sin \phi_1}{\sin \phi_2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

or

$$T_2 = \frac{T_1 \sin \phi_1}{\sin \phi_2}. \quad . \quad . \quad . \quad . \quad . \quad (32)$$

Introducing into this the correction for temperature, it becomes

$$T_2 = \frac{T_1 \sin \phi_1}{\sin \phi_2} \{1 + q(t_2 - t_1)\}, \quad . \quad . \quad . \quad (33)$$

where q is the fraction that expresses the decrease of magnetic moment of the needle for one degree increase of temperature—to be determined by experiment with the particular needle, as previously explained—and t_1 the temperature at the base station and t_2 that at any other. As $T_1 \sin \phi_1$ (observed at the base station) is a constant that enters into the observations of all other stations, let it be denoted by C_1; then equation (33) becomes

$$T_2 = \frac{C_1}{\sin \phi_2} \{1 + q(t_2 - t_1)\}. \quad . \quad . \quad . \quad . \quad (34)$$

This is a relative value of the intensity, dependent on that of the base station. If this had been compared with an observation made there with a unifilar magnetometer, C_1 would be known in absolute measure, and then T_2, T_3, T_4, etc., at all

other stations would be the Total Absolute Intensity proper to each locality, when freed from the effect of the ship's iron by means of the table of Intensity Deviations obtained from swinging ship.

The relation that the intensities are inversely as the *sines* of the angles of deflection will be evident when it is considered that with a less (magnetic) intensity, the same weight will produce a greater deflection.

SECOND, WITH DEFLECTORS: Remove the intensity needle A from the sockets and substitute needle B, without the silken fiber; when it has settled into the line of dip, adjust the circle at the back so that one of its screw-holes will lie in this line; place needle A in a cylindrical case provided for it and screw this into the hole in the line of dip with such pole toward the instrument that the needle B will be repelled by it; observe and record both ends of the needle: then by means of the disk J revolve *needle* B to the other side of the line of dip, symmetrical with its first position, and observe and record both its ends as before. From the readings in both positions of the needle is obtained the angle of deflection—the relation between the magnetic moment of the Earth and that of the deflecting needle A.

As in the first case, if this relation had been determined at a base station, we should have an equation similar to (34), that is,

$$T_2 = \frac{D_1}{\sin\theta_2}\{1 - q(t_2 - t_1)\}, \quad . \quad . \quad . \quad . \quad . \qquad (35)$$

in which the several symbols represent analogous quantities to those in the first case; and T_2 in equation (35) is either the relative or the absolute Total Intensity proper to the locality, according to the same circumstances as in that case.

THIRD, WEIGHT AND DEFLECTOR COMBINED: If the observations with weights and deflectors are carried out at the same station in the sequence and manner described, the one

—the ratio of the two forces, mechan... ... have from equa-
are in equilibrium. ...mber by member,

If this ratio had been determin... the same needle, and at the same ... . (36)
tion, and the magnetism of the n... the interval, the values of the inte... other station would be to each o... . . . . . (37)
the angles of deflection, or, den... ϕ_2, respectively, and the corres... T_2, we have ...naturally disappears;

... Absolute Intensity

$$\frac{T_2}{T_1} = \ldots$$

...previously stated. ... deflect the needle
or ... same needle A is used

$$T_2 = \ldots$$

... if the needle A should ... under the influence of
Introducing into this the ... less when used itself to
becomes ... magnetism of A remain

$$T_2 = \frac{T_1 \sin}{\sin \ldots}$$

... decrease, then the angle ... the first and second cases.

where q is the fraction
netic moment of the n... **Variation and Horizontal Com-**
perature—to be determ... **Shore with the Kew**
lar needle, as previousl... **Magnetometer.**
at the base station an...
observed at the base ... this problem is given in Part
the observations of al... phases here: the princi-
then equation (33) b... adjustments of the instrument,
... corrections to be applied to

$$T_2 = \ldots$$

...—This has been explained
This is a relative ... but for clearness it will be
the base station. ...
been made there ... sphere of influence just
known in abso... atmosphere: lines of force

esent the field of both; they are curved in every case, but : small area of the Earth they may be considered parallel. the dotted lines of Fig. 177 represent such an area on the izontal plane: the magnet A, suspended horizontally by read, will take the direction of these lines and be held there ι definite force. If another magnet B be brought near A, ield conflicts with that of A—in fact, both mingle with of the Earth, and a complex, contorted field is the result; ight be depicted to the eye by fine iron filings strewn on a

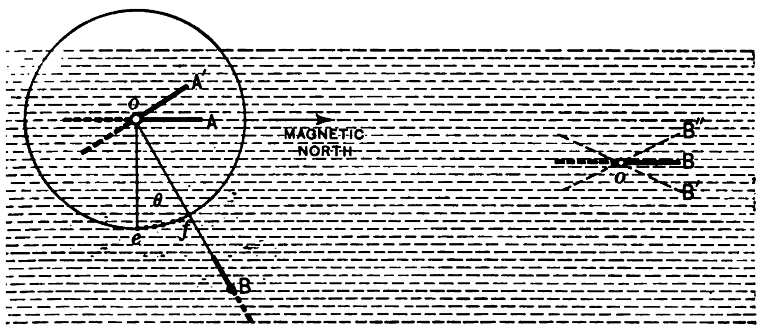


FIG. 177. FIG. 178.

et of paper above both magnets. The magnet A takes ew direction, A', in this distorted field: the terrestrial lines orce tend to bring it back to their natural parallelism, le those of B tend to urge it further away, and their bal- e at A' indicates the equality of both forces and gives the o of their strength; or $\frac{H}{M}$, if H denotes the strength of Earth and M that of B. This ratio becomes known by ling the angle *eof* on the horizontal circle of the instru- nt; it is equal to AOA', the deflection of the magnet A as s perpendicular to OA, and fO to OA', and the *sine* of this le is the ratio sought. Denote the angle by θ. Then we e

$$\frac{H}{M} = \theta. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (38)$$

With any change in either H or M—that is, a variation of the terrestrial field or of the strength of the magnet B, there will be a corresponding change in θ, so that this deflection becomes an exponent of the relative strength of both magnetic forces.

Now suspend B horizontally, as in Fig. 178, in the same field, and remove A beyond the power of influencing it. Let B be slightly deflected from its position of rest, and it will oscillate at a *certain definite rate* between the positions B' and B''. If the intensity of the Earth's field be doubled, it will act twice as forcibly on B; if trebled, three times; and if its intensity be represented by any arbitrary symbol H, it will act H-times: if, at the same time, the strength of the magnet B be doubled, this, too, will cause it to act twice as forcibly in the field H, that is, $2H$; if trebled, three times, or $3H$; and if its strength be denoted by any arbitrary symbol M, the force in action will be $M \cdot H$. Every change in either M or H will entail a change in the *rate* or *period* of oscillation; this period is timed by a chronometer, and it becomes an index of the combined force $M \cdot H$, that is

$$M \cdot H = t, \qquad (39)$$

the period of oscillation being t.

Multiplying equations (38) and (39) together, we have

$$\frac{H}{M} \cdot M \cdot H = \theta \cdot t, \qquad (40)$$

whence

$$H^2 = \theta \cdot t, \qquad (41)$$

and

$$H = \sqrt{\theta \cdot t}. \qquad (42)$$

Both θ and t are known from observation, and thus the horizontal intensity H, of the Earth's magnetic field is determined.

Dividing (39) by (38), we have

$$\frac{\frac{MH}{H}}{M} = \frac{t}{\theta}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (43)$$

whence

$$M^2 = \frac{t}{\theta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (44)$$

and

$$M = \sqrt{\frac{t}{\theta}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (45)$$

and thus we ascertain the strength of the magnet B.

The observation of the requisite quantities that enter into the equations consists therefore of two distinct operations—one of deflection and one of oscillation: the former will be described first.

It must be stated, however, that it is not a change in the magnetic forces alone that varies the rate of oscillation; but the material substance of the magnet itself enters as a factor with a specific rate of its own at a definite temperature, distinct and apart from any magnetic condition of the steel.

129. Description of the Kew Unifilar Magnetometer.—Fig. 179 represents the instrument, arranged for deflection: it consists of a graduated circle H, firmly supported on foot-screws; upon this is a circular plate provided with level, verniers, reading lenses, clamp, and tangent-screw—all for use with the circle; this system has motion round a vertical axis and carries with it the box F, to which is attached the tube U, and the bar R, set at right angles to the axis of the tube; the bar is removable; C is a carriage that may be slid along the bar—it bears the deflecting magnet B; G is a glass tube with a torsion apparatus P at the top, from which is pendant the suspension fiber of the magnet; to this magnet is attached a small mirror M, below and at right angles to its

axis; *E* is a telescope for viewing the image of the scale *S* reflected by the mirror as the magnet moves, and its eyepiece has a vertical wire for precision of observation.

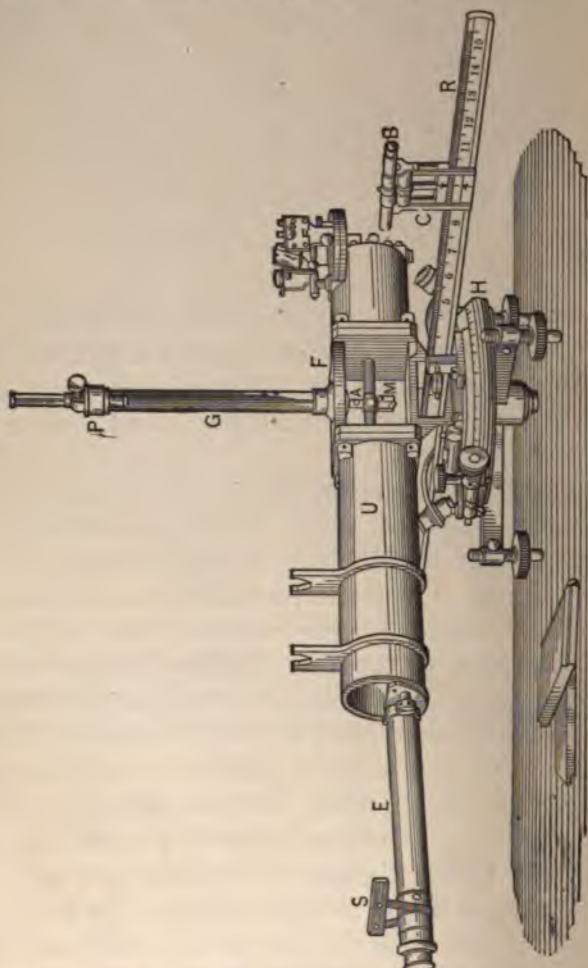


FIG. 179.

130. The deflection observation.—Level the instrument, turn the tube *U* into the magnetic meridian, remove the magnets, suspend the plummet *D*, Fig. 180, and let it hang until

twist is turned out of the fiber. Take off the plummet, spend the magnet A, level it by moving the little ring it rries, and put the wooden shutters on the box. By means the tangent-screw bring the vertical wire of the eye-piece

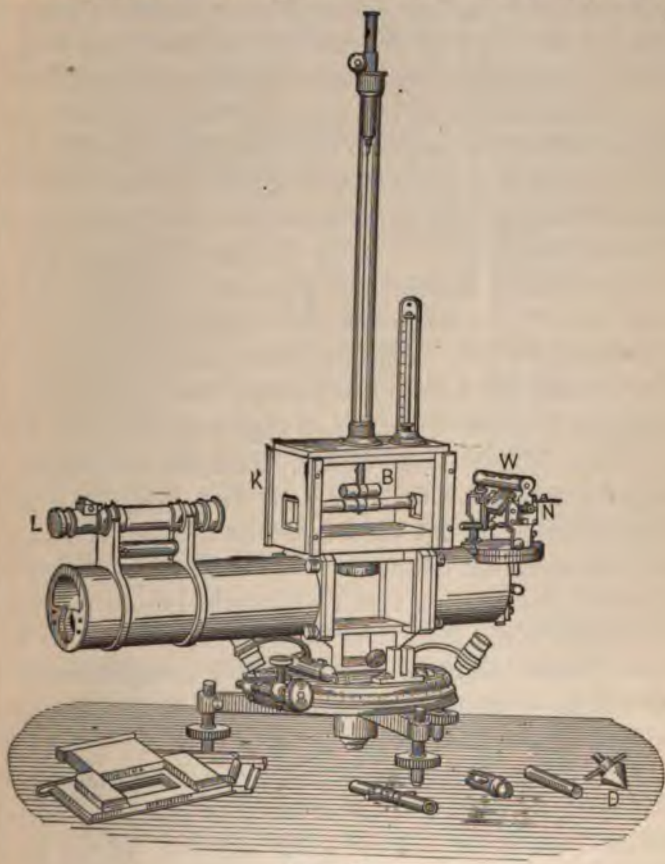


FIG. 180.

the telescope E into coincidence with the middle division the scale S, clamp the instrument, and read and record the rizontal circle and the middle division.

The temperature is to be recorded at every stage of the ocedure.

The deflecting magnet B may be used in one of two positions—either with its axis at right angles to that of the deflected magnet A, or perpendicular to the magnetic meridian: the former is best, being most effective, and produces less twist in the fiber; it alone will be described here; it introduces the *sine* of the angle of deflection—the other, the *tangent*.

Set the carriage at the proper distance on the bar, east of the meridian, and place the magnet B on it, north pole toward the suspended magnet: both magnets should be at the same level, which may be effected by the apparatus at P; the suspended magnet will be deflected and new divisions of the scale come into view. Unclamp and turn the upper structure until the middle division is brought into coincidence with the vertical wire of the telescope, then clamp, read, and record the horizontal circle. The difference between this and the former reading will be the first value of the deflection. Turn the magnet B on the carriage so that its south pole will act on A, and repeat the observation. Transfer the magnet and carriage to the same distance on the west side, and duplicate the observations already made. From all these readings the angle of deflection is deduced. Repeat all these observations at a second distance for data to compute the term involving the distribution of magnetism in A and B.

131. Proper distance for deflecting magnet, and best relative sizes of both magnets.—To obtain the best results, the length of B should be 1.224 times that of A; the former should not be brought nearer the latter than four times its own length, to deflect it; and the two distances at which deflections are made, should bear the ratio of 1.3 to each other.

To be specific, and illustrate the matter by magnets of very good dimensions: let A be a steel tube eight centimeters long, one cm. external diameter, and 0.8 cm. internal diameter; then B should be 10 cms. long, and the distances at

which it should be placed from A are respectively 40 and 50 cms., measured from center to center of both magnets.

But B must have good strength to produce sufficiently large deflections at these distances. It is immaterial about the magnetism of A—whether strong or weak, its deflection will be the same; whereas it is all-important that B should not only be strong, but also that it should preserve its magnetism without change.

132. To find the middle division of the scale and the angular value of one division.—Make the magnet A oscillate over a small arc; observe and record the extreme division that successively appears on the vertical wire during a number of oscillations, and take the mean of all the pairs right and left: it will be the middle division.

Next turn the upper system until a part of the scale near one end comes into view, when note the particular division in coincidence with the vertical wire of the eye-piece, and read the horizontal circle; then turn the system until the other extreme of the scale appears, when repeat the observation just made: the difference of the horizontal-circle readings divided by the difference of the scale-division readings will be the value in arc of one scale division.

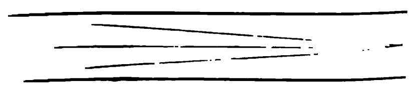
133. A quartz fiber the best—how to make it.—If the suspension fiber be of silk, moisten it with a drop of glycerine: this will reduce and equalize the torsional rigidity.

But the best material is a quartz fiber, on account of its lightness, strength, and extreme flexibility. It may be made thus: attach a bit of quartz to the arrow of a cross-bow, melt it in the oxyhydrogen blow-pipe and, at the proper point of fusion, discharge the arrow, when it will spin the globule of quartz into a filament whose fineness depends on the rapidity of the arrow's flight.

134. The most suitable time for magnetic observations.—The best time for making observations with the Kew magnetometer is from 7 to 10 a.m.—beginning with Deflections,

...ng with the Variation:
... nearly calm and closest

...—For Oscillation the
... Fig 180.
... the meridian, remove
... both magnets. Set the
... the glass tube into it;
... fiber untwist itself; place
... level the instrument; re-
... B which was used to pro-
... a steel tube having a small
... the other that renders the
...el on passing through it—
... scale corresponding to the



...

... found, as it is the mark to
... the process is identical with
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...sition and also inverted, or
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... magnet A.
...*ation*—which is the quantity
...itude of the arc over which
...mits of this at beginning and
...served and recorded, in order
...uce it to an arc whose period

... the magnet at rest with the
... vertical wire of the telescope.

bring a small weak magnet toward the middle of the suspended magnet and at right angles to the meridian, and when the requisite deflection is produced, remove the small magnet quickly, and let the other swing until the arc is reduced

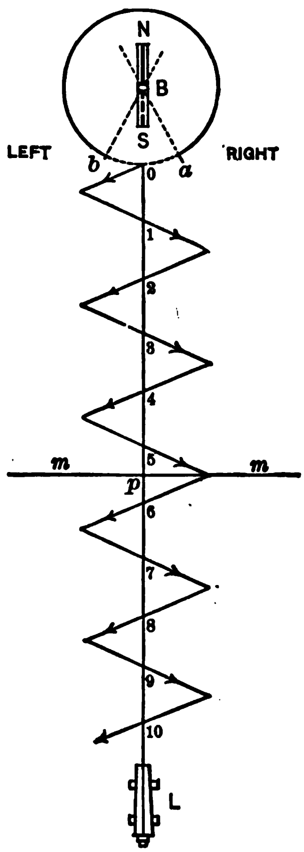

FIG. 182.

to less than 2° on each side, when, the movement being regular and steady, the counting of the oscillations may begin.

136. Method of counting the oscillations, and meaning of "one oscillation."—Consider Fig. 182 where *B* represents the magnet swinging through the arc *ab*; the zig-zag line

represents its successive oscillations, L the telescope, and 1, 2, 3, . . . 10 the intervals at which the magnetic axis of B crosses the line of sight: at each of these the observer at L calls out "Mark!" to an observer at a chronometer, who notes and records the time; then, without observing for about two minutes, the magnet is allowed to continue its oscillation, and again the times of ten more transits are observed and recorded, beginning and ending with the magnet moving in the *same direction* as during the first series; repeat this proceeding until three intervals of rest of two minutes each alternate with four sets of ten transits each.

Then it is evident that in each series of ten transits, the mean of the 5th and 6th will give the time of a midway point p on the line mpm—that is, a specific, midway point of *time;* so will the mean of the 4th and 7th; 3d and 8th; 2d and 9th; 1st and 10th: all give the same point—the same time.

The interval between any two successive transits—as 1 and 2; 2 and 3; 3 and 4; and so on—is called the time of a *half oscillation:* and the interval between any two alternate transits—as 1 and 3; 2 and 4; 3 and 5; and so on—is called the time of "ONE OSCILLATION." Deduce this time of one oscillation from each of the four series of ten transits—it should be nearly the same for all; take the mean of the four values. Find from the first and fourth series of transits the time of the middle point p; take the difference between these two times; convert this difference into seconds and divide it by the time of one oscillation deduced from the mean of the four values stated above: the quotient is the number of complete oscillations ("one oscillation" each) that occurred between the point p in the first series of transits and the point p in the last series—it should of course be a whole number, but may not be, but a whole number and fraction—owing to the inexactness of marking the times of transit, for they will scarcely occur at exact seconds. The decimal part will be so close to a whole number, however,

that the nearest *whole number* is to be taken as the entire number of oscillations between the point p in the first and fourth series of transits. Divide the interval in seconds between the time of this point p in the first and last series by the *whole number* of oscillations made during it, and the result will be the *time of "one oscillation,"* which is the quantity sought.

137. **Corrections.**—The quantities obtained by observation require several corrections, which will now be explained.

1ST. TORSION OF SUSPENSION FIBER.—If a brass bar be hung horizontally by a stout steel wire and set in oscillation, it will swing to and fro for a short time, and then come to rest in a definite direction—that for which the wire is devoid of twist; and the rigidity of the wire will keep it in that direction.

If the bar be turned round the wire as an axis, this act will twist the particles of the wire from a condition of parallelism to its own length into one of spiral curves, and the effort of the particles to recover their original alignment is equivalent to the force of torsion: this varies with the angle of deflection, size of the wire, and material of which it is made, and exists to some degree in every material used for suspension—wire, silk, or quartz.

In the deflection experiment, the force of torsion opposes the force of the deflecting magnet, and so the angle is lessened by a very small amount: in the oscillation experiment, it conspires with the Earth's magnetic force to quicken the rate of oscillation, and its effect must be removed from the observed time to get that due to magnetism alone. Thus the moment of torsion, though a mechanical one, is, in its action on the bar, entirely analogous to the magnetic moment of the Earth.

To determine the force of torsion: with the magnet B suspended, bring its axis into coincidence with the vertical wire of the telescope L, both being in the magnetic meridian, and

the fiber free from twist; turn the torsion circle P to the right 90° and observe and record the new division of the scale that comes upon the vertical wire; turn the torsion circle 90° to the left and repeat this observation: convert the scale deflection into angular measure—denote it by a—and then, F being the force of torsion and $m \, . \, H$ the combined magnetic force of Earth and B we have, when the forces are balanced against each other, as just described,

$$\frac{F}{m \, . \, H} = \frac{a}{90^\circ - a} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (46)$$

2D. RATE OF THE CHRONOMETER.—The observed period of one oscillation will be affected by a proportionate amount of whatever change occurs in the daily running of the chronometer: if this be gaining, the period will be shorter than if the chronometer were running uniformly, and hence the correction must be added or is plus (+); if losing, the period will be longer, and hence subtractive or minus (—); let s denote the daily rate, then 86,400 being the number of seconds in a day, the correction is $\pm \frac{s}{86{,}400}$, to be applied to the observed time of one oscillation.

3D. REDUCTION TO SMALL ARC.—That the time of oscillation decreases with a lessening arc of swing is a matter both of demonstration and experimental proof.

The damping of the magnet's motion—the logarithmic decrement, as it is called when a regular decrease, because the phenomenon may be represented by a logarithmic equation and curve, is due to a combination of causes—rigidity of the fiber, resistance of the air, and opposing electric currents excited in surrounding metals.

Through whatever arc the magnet oscillates, its period, therefore, must be reduced to that of an arc whose period is constant: an arc of one degree is practically such. The initial and terminal arcs of oscillation, denoted respectively

c_1 and c_2, must be expressed in parts of the radius (not legrees or scale divisions) and the correction to be applied :he observed time of one complete oscillation is

$$\left(-\frac{c_1 c_2}{16}\right). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (47)$$

4TH. THE EARTH'S INDUCTION ON THE MAGNET USED FOR 'LECTING AND OSCILLATING.—When a steel magnet is ught into a magnetic field, its own strength undergoes a nge whose amount depends upon the intensity of the field,

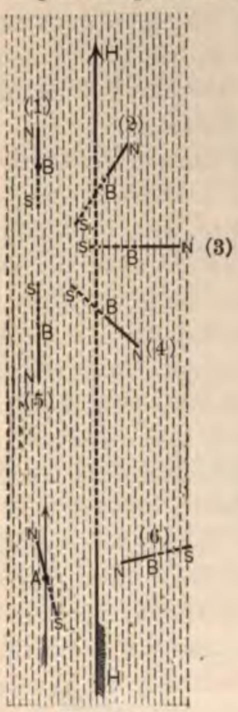

FIG. 183.

direction of the magnet's axis with reference to the lines force of the field, the temperature, and the hardness of steel.

Fig. 183 represents the Earth's horizontal magnetic field, with a magnet B in various positions in it: in (1) it receives

the full strengthening effect; in (2) the effect is less and continues to decrease to position (3), where, being exerted across the magnet, there is none at all in the direction of the axis; in (4) the tendency is to diminish the strength of the magnet, and this increases to a maximum at (5), where the poles are placed opposite to their position in (1).

During oscillation, the magnet *B* occupies a mean direction similar to (1), while in deflecting, its position is like (6), but little different from (3): thus B acquires different values in both experiments, which will not cancel in the final equations; they must be equalized by corrections for induction; that for deflection is extremely small, and that for oscillation the one most to be considered.

Let μ represent the *induction* due to a field of unit intensity in dynes: such a field—or one greater, or less—can be excited inside a coil of wire by sending an electric current through it, and the intensity of this field can be accurately measured. Place such a coil at right angles to the magnetic meridian at a measured distance from a short suspended needle, and send a current through it; observe the deflection (if any) and the intensity of the field, also the temperature. Then put the magnet *B* inside the coil, send the same current through it, and observe the same quantities as before. The tangents of the angles of deflection in both cases compared with the tangent of the angle produced by *B* alone at the same distance, afford the data for determining the inductive effect of the field upon *B*; and this may be done and tabulated for several intensities and temperatures.

The horizontal intensity at Washington is about two-tenths of a dyne, and an artificial field much stronger than this may be produced in a helix at such distance from a small needle as not to deflect it, while a magnet like *B* at the same distance would produce deflection; and it requires a field of at least two dynes to cause a permanent change in the magnetism of a glass-hard steel magnet.

e value of H (the Earth's field), *its i.* *ermanent moment M of the magnet B* lating, then, since B has the position he result of the moment $M \cdot H$ alone t 'ate of oscillation, but of the moment

$$\mu \cdot H), \quad \text{or} \quad H \cdot M\left(1 + \frac{\mu \cdot H}{M}\right), \quad . \quad (4$$

ince B has position (6), Fig. 183, its mo-

$$M - \mu \cdot H \sin y, \quad . \quad . \quad . \quad . \quad . \quad (49)$$

:he two magnets A and B being at right

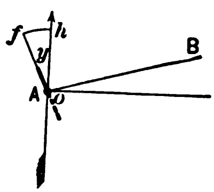

FIG. 184.

:her, if we resolve the horizontal intensity oh endicular to the axis of B, we have fh and of; o *the axis of B*, alone produces change in the t of B, and since $\widehat{oh}$ equals $\mu \cdot H$, the strength field; whence expression (49).

$$34, \sin y = \frac{\widehat{fh}}{\widehat{oh}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (50)$$

$$\widehat{fh} = \widehat{oh} \sin y, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (51)$$

$$\widehat{fh} = \mu \cdot H \cdot \sin y, \quad . \quad . \quad . \quad . \quad (52)$$

Where electrical means are not available for produc ing fields of different intensity, the effect of the natural ter restrial field can be determined with the magnetometer itsel as follows:

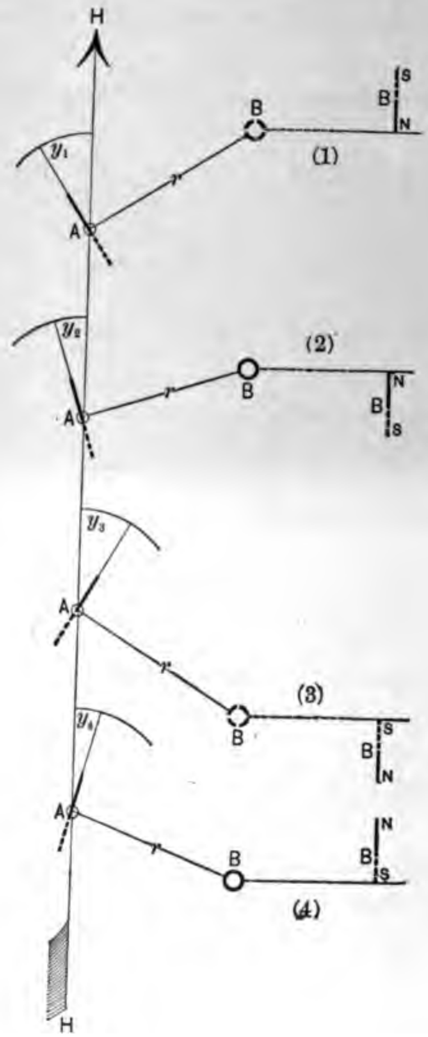

FIG. 185.

In Fig. 185 let the plane of the paper represent a horizontal surface with the magnetic meridian *HH* traced upon it; *A* the magnet suspended in its box, and (1), (2), (3), (4) successive positions of B, placed vertically at right angles to the axis of *A*, with its *acting pole on a level with A*: the latter will be deflected. In each case, both before and after deflection, bring the middle division of the scale into coincidence with the vertical wire of the telescope, and observe and record the horizontal circle, to get the angle of deflection: in (1) with the north pole of *B* in plane of paper and south pole uppermost, *A* will be deflected to the west and most strongly, because the Earth's induction on *B* strengthens its poles; in (2) *A* will be deflected to the west also, but less than in (1), because, while the north pole is still in the plane of the paper, it is now uppermost and the effort of the Earth is to diminish the magnetism of *B*; in (3) the south pole of *B* is in the plane of the paper and uppermost—*A* will be deflected to the east, and most strongly; and in (4) the south pole is in the plane of the paper, north pole uppermost and the deflection will still be to the east, but less so than in (3). Let *M* represent the *permanent* magnetic moment of *B* at the time of observation; M' that of *A*; dM the change in moment of *B* due to the Earth's induction; and y_1, y_2, y_3, y_4, the deflections in the previous four cases respectively: then in (1) and (3), Fig. 185, these are due to increased moments, and in (2) and (4) to diminished ones; or,

$$M + dM = y_1, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (53)$$

and

$$M - dM = y_2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (54)$$

Subtracting latter from former, we have

$$2dM = y_1 - y_2, \quad . \quad . \quad . \quad . \quad . \quad (55)$$

whence

$$dM = \tfrac{1}{2}(y_1 - y_2), \quad . \quad . \quad . \quad (56)$$

and similarly,

$$dM = \tfrac{1}{2}(y_3 - y_4). \quad . \quad . \quad . \quad (57)$$

Adding (56) and (57),

$$2dM = \tfrac{1}{2}(y_1 - y_2) + \tfrac{1}{2}(y_3 - y_4), \quad . \quad . \quad (58)$$

or

$$dM = \tfrac{1}{4}(y_1 - y_2 + y_3 - y_4) = dy; \quad . \quad . \quad (59)$$

that is, let the second member of this equation equal dy, and then it is the mean value of the *change* in the angle of deflection due to the *change* dM in the moment M of the magnet B.

Again: $\frac{1}{2}(y_1 + y_2)$ is the deflection to the west, and $\frac{1}{2}(y_3 + y_4)$ to the east, and

$$\tfrac{1}{2}\{\tfrac{1}{2}(y_1 + y_2) - \tfrac{1}{2}(y_3 + y_4)\} = \tfrac{1}{4}(y_1 + y_2 - y_3 - y_4) = y; \quad (60)$$

that is, let the second member of equation (60) equal y, and then this is the mean value of the angle of deflection. Now in each case, as shown in Fig. 186, it is the magnetic moment of B acting at the distance r on the moment of A, that balances this magnet against the magnetic moment of the Earth: resolving the Earth's moment H (or $\overline{fH}$ in Fig. 186) into two others, fg and fh, the latter alone is effective in turning A: hence when equilibrium occurs, we have

$$M \,.\, M' \,.\, r = M' \,.\, \widehat{fh}, \quad . \quad . \quad . \quad . \quad . \quad (61)$$

or

$$M \,.\, r = \widehat{fh}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (62)$$

The distance r should be several times the length of the *deflecting* magnet.

Now in Fig. 186

$$\sin y = \frac{\overline{fh}}{\overline{oh}} = \frac{\overline{fh}}{H}; \text{ hence } \overline{fh} = H \,.\, \sin y, \quad . \quad (63)$$

and therefore from (62),

$$M \,.\, r = H \,.\, \sin y. \quad . \quad . \quad . \quad . \quad . \quad (64)$$

Differentiating this with respect to the variables M and y, we have

$$r \,.\, dM = H \,.\, \cos y \,.\, dy, \quad . \quad . \quad . \quad . \quad (65)$$

dividing this by (64), we have

$$\frac{r \,.\, dM}{r \,.\, M} = \frac{H \,.\, \cos y \,.\, dy}{H \,.\, \sin y}, \quad . \quad . \quad . \quad . \quad (66)$$

whence

$$\frac{dM}{M} = \cot y \,.\, dy. \quad . \quad . \quad . \quad . \quad . \quad (67)$$

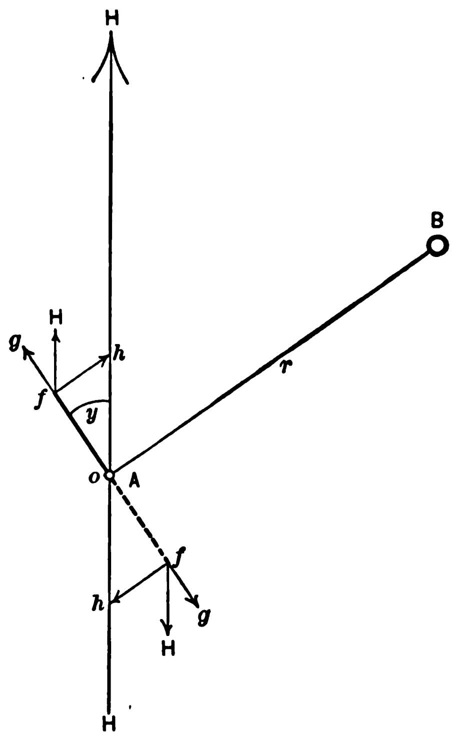

FIG. 186.

That is to say, the first member of eq. (67) gives the *change* of moment of *B* in terms of its permanent moment.

Both y and dy are known from (59) and (60), so that $\frac{dM}{M}$ is determined; but this is the effect of the vertical component *Z* upon *B* as illustrated in Fig. 185, that is, expressing the

vertical component in dynes in terms of the permanent moment of B, we have

$$\frac{dM}{M} = \frac{\mu . Z}{M}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (68)$$

or from (67)

$$\frac{dM}{M} = \frac{\mu . Z}{M} = \cot y . dy, \quad . \quad . \quad (69)$$

whereas it is the effect of the horizontal component, similarly expressed, or $\frac{\mu . H}{M}$ on B, as illustrated in Fig. 183, that is wanted. This latter is found by means of the Dip; for in Fig. 187,

$$\cot D = \frac{H}{Z}, \quad \text{or} \quad H = Z . \cot D, \quad . \quad . \quad (70)$$

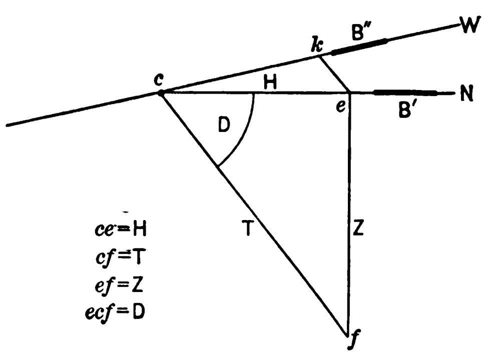

FIG. 187.

multiplying both sides of eq. (70) by $\frac{\mu}{M}$ it becomes

$$\frac{\mu . H}{M} = \frac{\mu . Z}{M} . \cot D; \quad . \quad . \quad . \quad . \quad . \quad (71)$$

then from (69) and (71) we have

$$\frac{\mu . H}{M} = \cot y . dy . \cot D, \quad . \quad . \quad . \quad (72)$$

the value required for eq. (48) as the effect of induction on B *when oscillating*, or in the mean position B' in the magnetic meridian in Fig. 187; and the effect of the same magnet *when deflecting* at any angle *kce*, as at B'' Fig. 187, may be found by resolving the value in equation (72) parallel and perpendicular to the *axis of* B'', when the *former component* will be the effective one, producing induction at that angle.

5TH. MOMENT OF INERTIA.—The force of torsion was illustrated by the oscillation of a brass bar suspended by a steel wire: let such a bar be set in motion and it will swing to and fro under the influence of torsion of the wire precisely as a magnet would under the influence of terrestrial magnetism. The brass bar will have a certain *rate* of oscillation, just as the magnet will, or the steel tube of which the magnet is made, *would*, if wholly deprived of its magnetism. Once set in motion, the brass bar possesses a store of energy that keeps it going until dissipated by the rigidity of the suspension wire, friction of the parts, and resistance of the air: this potential energy may be called the Moment of Inertia—that is, a kind of power to keep going, or rather, inability to stop of its own accord—the inertia of matter in motion that still keeps it moving. It is a quantity as definite as any real force, and whether the moving mass be copper, steel, or ivory, it has a period of oscillation as specific and calculable as the period of a magnet; and, in fact, inert though it be, and due to mere bulk and form of steel in the magnet—it is yoked to its active mate—magnetism, to produce the *observed* rate of oscillation of the magnet: its quota must be separated from this observed rate, for it is the portion due to magnetism alone that we are in quest of.

Defined mathematically, the moment of inertia of a body with respect to an axis through its center of gravity, round which it may oscillate, is equal to the sum of the products of two quantities, viz., the mass of the elementary particles and the square of the distance of each one from the axis: or,

denoting the moment of inertia by K, the distance by h, and the mass of a particle by ds, we have

$$K = \int h^2 . ds, \quad . \quad . \quad . \quad . \quad . \quad . \quad (73)$$

in which the integration is to be extended to the limits of the body.

Many of the corrections have a varying value with different temperatures, and the moment of inertia is one: to be specific, then, a standard temperature must be fixed, to which all reductions are made; suppose it 0° Centigrade. With increased heat the metal expands, the distance of each particle becomes greater, and this alters the value of K; so that by observing the temperature during oscillation and knowing the coëfficient of expansion of steel, this correction is readily made:

6TH. CHANGE IN MAGNETIC MOMENT OF B DUE TO TEMPERATURE.—The magnetism of every magnet varies with the temperature—increasing with cold, diminishing with warmth, and always returning to the same condition at the same temperature; the magnetic moment is specific, then, only when we know the temperature at which it was determined; moreover, every magnet has its own ratio of change, dependent on the quality and temper of its steel; even this ratio is not constant at all temperatures: and therefore the peculiarities of each magnet must be experimentally determined.

This can be done with the magnetometer itself: suspend A and use B to deflect it, always with the axes of both at right angles to each other. Means are to be provided for surrounding B (placed on its carriage) with water at different temperatures—say, ice-cold, the boiling point, and two intermediate states; a thermometer should be immersed to indicate the exact temperature. At each stage, the middle division of the scale is to be brought into coincidence with

the vertical wire of the telescope, the horizontal circle read, and the magnet B turned so that each pole will act successively in deflecting A—the distance between the centers of both magnets remaining unchanged.

As with the effect of terrestrial induction on the moment of B, the change due to varying temperature is a differential one, and the analytical treatment of the matter is analogous to that: here, as there, it is the moment of B that successively changes—here by heat, there by induction, and at each change balances A against the Earth's magnetic couple; so that equation (61) expresses the condition of equilibrium, and (67) the relative change at different temperatures in terms of the moment at the standard temperature. Both y and dy, as in the case of induction, are given by observation of the horizontal circle at each stage of the water.

The following is an empirical formula that is quite accurate for calculating the correction:

$$M_0 = M_1[q(\tau_0 - \tau_1) + q'(\tau_0 - \tau_1)^2], \quad . \quad . \quad (74)$$

in which M_0 is the magnetic moment at the standard temperature τ_0 and M_1 the observed moment at any temperature τ_1 above it.

Since $MH = \frac{\pi^2 k}{t^2}$ (see Part Sixth), therefore, any *de*crease in M causes a corresponding *in*crease in t^2, so that the correction must be applied to the square of the period of oscillation in the inverse direction.

7TH. GRADUATION OF THE BAR R.—When an instrument is purchased, a statement accompanies it of any defect found by test in the graduation of the bar R used for measuring the distances between the two magnets in deflection experiments. As the bar is of metal, it becomes longer with heat and shorter with cold, thus giving a variable distance with different temperatures: observing the latter and knowing

the coëfficient of expansion of the metal from tables easily accessible, this correction is readily applied.

8TH. DISTRIBUTION OF MAGNETISM IN THE MAGNETS A AND B.—The "magnetic moment" of a bar and the "moment of the Earth's magnetic couple" are phrases that have been frequently used in this chapter: it now becomes necessary to acquire exact ideas of them.

In mechanics a couple consists of two equal forces acting at the ends of a lever in opposite directions so as to give it rotary motion round an axis through its center—Fig. 188:

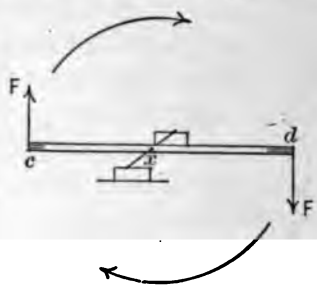

FIG. 188.

the moment of the couple is the sum of the products of each force into the arm it acts upon, thus in Fig. 188,

$$F \, . \, \widehat{cx} + F \, . \, \widehat{xd} = F(\widehat{cx} + \widehat{xd}) = F \, . \, \widehat{cd}, \quad . \quad . \quad (75)$$

and the last form of this expression is the one usually defined as the moment of a couple—that is, the product of one of the forces into the distance between them.

In Fig. 189, the parallel lines represent the Earth's magnetic field in which the magnetized bar NS is suspended horizontally by a thread and forcibly held at an angle θ with the lines. *Heretofore, the magnetism of the bar has been supposed concentrated in two points—the poles—one at each end, and of equal strength;* denote this strength of pole by m'. The magnetism of the field is uniform—the same around N, around S, and at every intervening point; denote it by H. The effort

of the field is to turn the bar round the thread as an axis, and the appropriate definition of this, is a couple: the force at each end is made up of two components—the magnetism

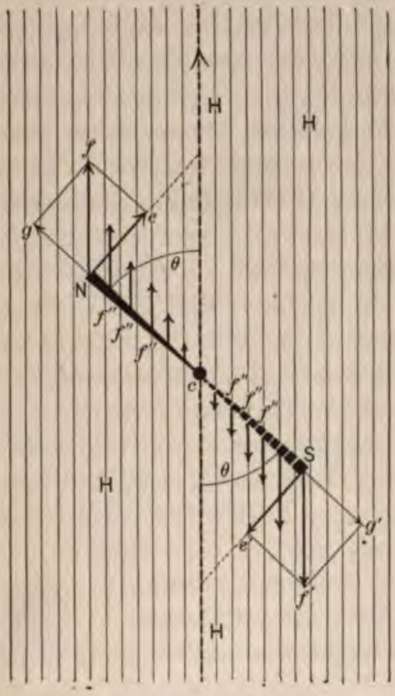

FIG. 189.

(m') of the bar and that (H) of the Earth; represent it by Nf and Sf'; but the effective part of H at right angles to the axis of the bar is $H \sin \theta$; hence the effective force at each end is $m'. H. \sin \theta$, and if the length of the bar be denoted by l, the magnetic moment acting upon it, is

$$m' . l . H . \sin \theta . \quad . \quad . \quad . \quad . \quad . \quad . \quad (76)$$

The product of the strength of one pole into the length of the bar—or, $m'. l$—is the magnetic moment of the bar;

the coëfficien ... two equal forces act-
accessible. ... the magnet—forms,
8TH. Di ... between them, the moment
AND B.—Th ... the bar.
ment of the ... magnetism of *the bar is con-*
been frequen ... according to fact: the
sary to acqu ... magnetism is *distributed* through-
In mech ... strewing iron filings around
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... be represented by the
... Fig. 189, so that every
... side of the middle point C,
... uniform force H, a couple
... between them for a lever. It
... that is expressed by (76)
... very closely to the truth
... very hard steel, magnetized
... not know that it will equally
the mom ... distribution, as far as our
force int ... ding to the general case, but
... one; moreover, when two
... other, as in the deflection
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netism ... All the formulæ upon which
and a ... their arrangement for practical
... in Part Sixth.

138. To determine the Variation with the Kew Magnetometer.— The observation for Variation may follow the oscillation experiment, as the instrument is still suitably arranged therefor.

Referring to Fig. 180, it will be seen that N is a small plane mirror firmly fixed to an axle below the level W; when the magnet is raised to the top of the box by the apparatus at P, it leaves a clear passage for an image of the Sun to be reflected by the mirror into the telescope L.

The mirror must be adjusted in three essential particulars: 1st, its axle made horizontal—indicated by the level above it; 2d, its surface made parallel to the axle; and 3d, its plane rendered perpendicular to the line of collimation of the telescope. The telescope is furnished with a collimating eyepiece, by which, when the plane of the transit mirror is vertical, the image of the wire of the telescope will be seen by reflexion. By means of the proper screws, the 2d and 3d adjustments may be effected by making the wire (seen directly) coincide with its reflected image before and after reversal of the transit axis.

With the magnet still drawn close up to the top of the box, turn the upper structure round its vertical axis and the mirror on its axle until the Sun appears in the field of the telescope approaching the vertical wire; then clamp the instrument and read and record the verniers of the horizontal circle. As each limb of the Sun touches the vertical wire, note the instant of contact by chronometer, and take the mean as the time of transit of the Sun's center.

139. To find the true meridian.—From the mean of the observed times, the apparent time of transit of the Sun's center—the hour angle—may be obtained; and with the declination from the Nautical Almanac, and the latitude of the place known, the true azimuth of the Sun may be calculated by Napier's analogies (Chauvenet's Trig., Ed. 1862, p. 160, [42] and [43]) as follows:

$$\tan \tfrac{1}{2}(A + B) = \frac{\cos \frac{1}{2}(a - b)}{\cos \frac{1}{2}(a + b)} \cot \tfrac{1}{2}C, \quad . \quad . \quad (77)$$

$$\tan \tfrac{1}{2}(A - B) = \frac{\sin \frac{1}{2}(a - b)}{\sin \frac{1}{2}(a + b)} \cot \tfrac{1}{2}C, \quad . \quad . \quad (78)$$

$$A = \tfrac{1}{2}(A + B) + \tfrac{1}{2}(A - B). \quad . \quad (79)$$

The problem is illustrated by Fig. 190, where SPZ is a

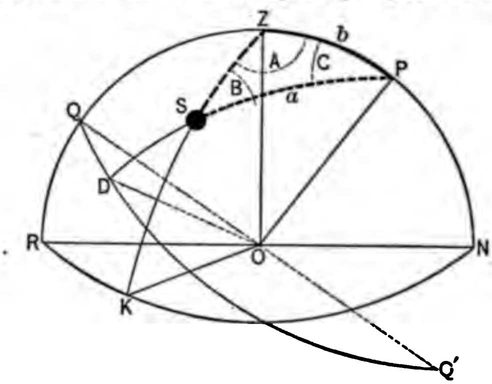


FIG. 190.

spherical triangle formed by great circles through the pole of the Earth, the zenith of the observer, and the Sun: RKN is the plane of the horizon and QDQ' that of the Equator; S is the position of the Sun, C the hour angle, A the true azimuth, SP $(= a)$ the polar distance, and PZ $(= b)$ the colatitude.

140. To find the magnetic meridian.—The observation of the Sun being completed, lower the magnet, unclamp and turn the upper structure until the middle division of the magnet-scale comes upon the vertical wire, when replace the magnet by the plummet D and let it hang until all twist is turned out of the suspension thread; this will be indicated by the little bar of the plummet remaining steadily on the vertical wire; then suspend the magnet again, and by means of the tangent-

screw bring the central division of the scale into exact coincidence with the vertical wire; read and record the verniers of the horizontal circle; revolve the *magnet* round its own axis through 180°, bring the central division again into coincidence with the vertical wire and read and record the horizontal circle: these two readings will correct any want of coincidence of the magnetic axis with the middle division of the scale. This is shown in Fig. 191: if the magnetic axis is

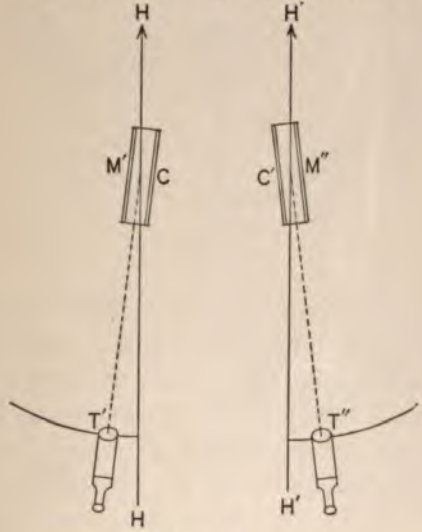


FIG. 191.

not identical with the axis of figure, the magnet will hang as at M' and in order to have the vertical wire coincide with the middle division of the scale, the telescope must be moved out of the magnetic meridian HH by a small angle to T'; when the magnet is turned upside down, it will swing as at M'', and the telescope will have to be moved to T'' at an equal angle on the other side of the meridian: the mean of these two angles will give the correct reading of the meridian on the horizontal circle, thus eliminating any irregularity of direction of the magnetic axis in the bar.

141. The Variation deduced.—With the data thus obtained, the Variation is easily gotten. Projecting Fig. 190 on the plane of the horizon, it becomes Fig. 192: in this, S

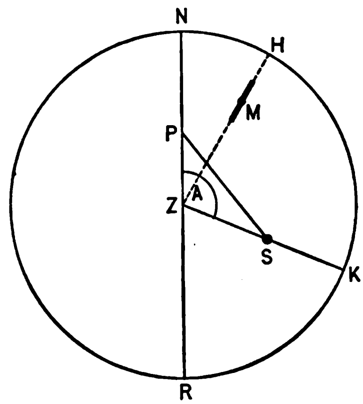
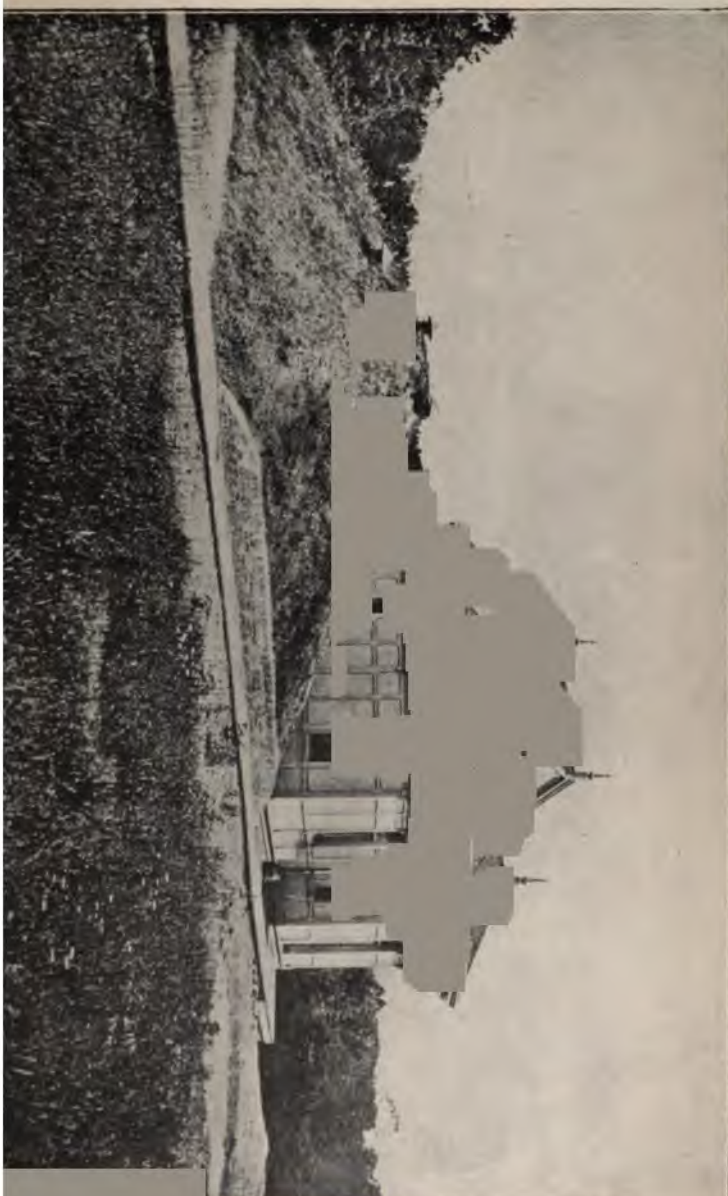


FIG. 192.

is the Sun when observed, and K is the reading of the horizontal circle corresponding to the vertical plane through the Sun and axis of the telescope; SZP, the true azimuth of the Sun, is the angle A obtained by calculation; applying it to the reading K, we get the point N or reading of the horizontal circle corresponding to the true meridian: the point H is the mean of the readings of the horizontal circle when the middle division of the magnet-scale was observed in its two positions—Fig. 191; it is the direction of the magnetic meridian: hence the difference of the readings N and H gives the angle NZH, that is, the Variation.

142. Precautions to be taken.—In all observations with magnetic instruments, keys, pocket-knives, steel frame eyeglasses or any other material containing steel or iron should be removed from the observer and well away from the instrument.

Plate B.—U. S. Naval Observatory, Washington, D. C., Magnetic Observatory in Foreground.



Section Five: To Determine the Variation and Horizontal Intensity on Shore with the U. S. Coast Survey Altazimuth and Magnetometer.

143. This method and the instruments used are fully described and illustrated in publications of the U. S. Coast and Geodetic Survey, Washington, D. C., entitled "Appendix No. 14—Report for 1880" and "Appendix No. 8—Report for 1881." These can, no doubt, be had by application to the Superintendent: it would therefore be unsatisfactory to give here in abridged form what may easily be obtained in its entirety.

The Coast Survey has had long and varied experience in magnetic observations, the results of which are embodied in its publications with full detail and scientific accuracy: hence to observers contemplating work of this kind—who have both instruments and methods to choose, *ab initio*—those of the Coast Survey are accessible, reliable, and practical.

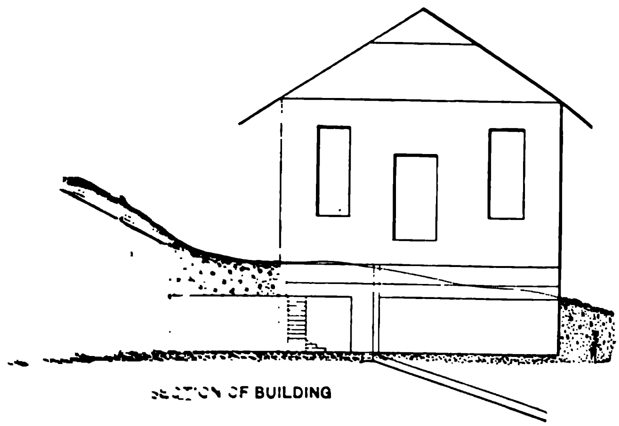
Section Six: Magnetographs and Other Instruments in Permanent Observatories.

144. Magnetic Observatories.—In 1806, Humboldt established in Berlin the first magnetic observatory; since then they have multiplied, and to-day may be found not only under government control in almost every capital, but also connected with colleges in various places: they dot the globe, and their accurate and continuous records exhibit every fluctuation of the great magnetic atmosphere surrounding the Earth.

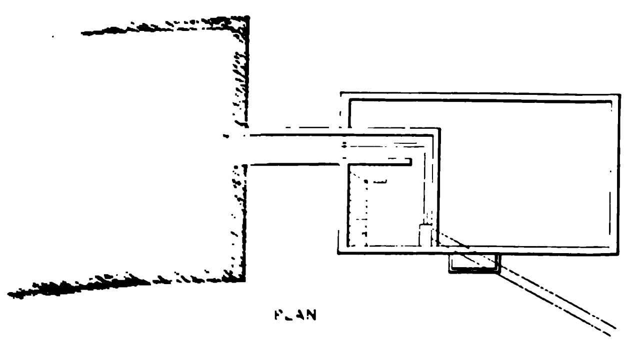
145. The Magnetic Observatory at Washington.—Plate B is a picture of the U. S. Naval Observatory at Washington, with the Magnetic Observatory in the foreground; Plate C

… building itself with the mound
… vault containing the magneto-
… section and plan of both building

Plate D



SECTION OF BUILDING



PLAN

… the latter for the instruments.
… wood and copper, the vault of brick
… for the instruments, granite: all
… magnetically before being used.
… enters into the construction or

equipment. In the vault means are provided for a continuous supply of dry, pure air of a nearly constant temperature.

146. The Magnetographs.—The principle of these instruments consists in the movement of a suspended magnet being delineated upon a roll of sensitized paper by the reflexion upon it of a ray of light from a mirror fixed to the magnet.

Plate E gives a general view of the apparatus as mounted in the vault, and Plate F an enlarged illustration of the most important parts.

These magnetographs, the building shown in Plate C, and the large variation magnet, Plate G, with some other instruments, form the establishment and equipment of the Magnetic Observatory for the Government as designed and partly carried out by the writer of this Treatise, and to which reference has been made in another part of the work.

In the description that follows of Plates E and F, the same figures and letters apply to identical parts in both: (1), (2), and (3) represent magnets variously suspended and covered by glass receivers; these rest on circular brass boxes, the bearing surfaces being ground smooth, and the air exhausted from the receivers, so that the magnets move *in vacuo*. Certain fittings accompany each magnet, whose function is the same for all: viz., a copper frame *D* in which electric currents are excited by the motion of the magnet, that reduce and steady its oscillations; a circular plane mirror *M*, in two parts—one firmly attached to the magnet and so moveable with it, the other fixed to a stationary support; a gas flame *L* whose rays are concentrated by means of various lenses into a short line of light that proceeds through the pipe *P* to the mirror, and is thence reflected through the tube *T* upon a roll of photographic paper in the box *K*; a telescope *H* with graduated scale *S* for observing directly the magnet's position.

The rolls of paper are revolved by clock-work, as seen in (4), and in addition to the traces of the magnet's oscil-

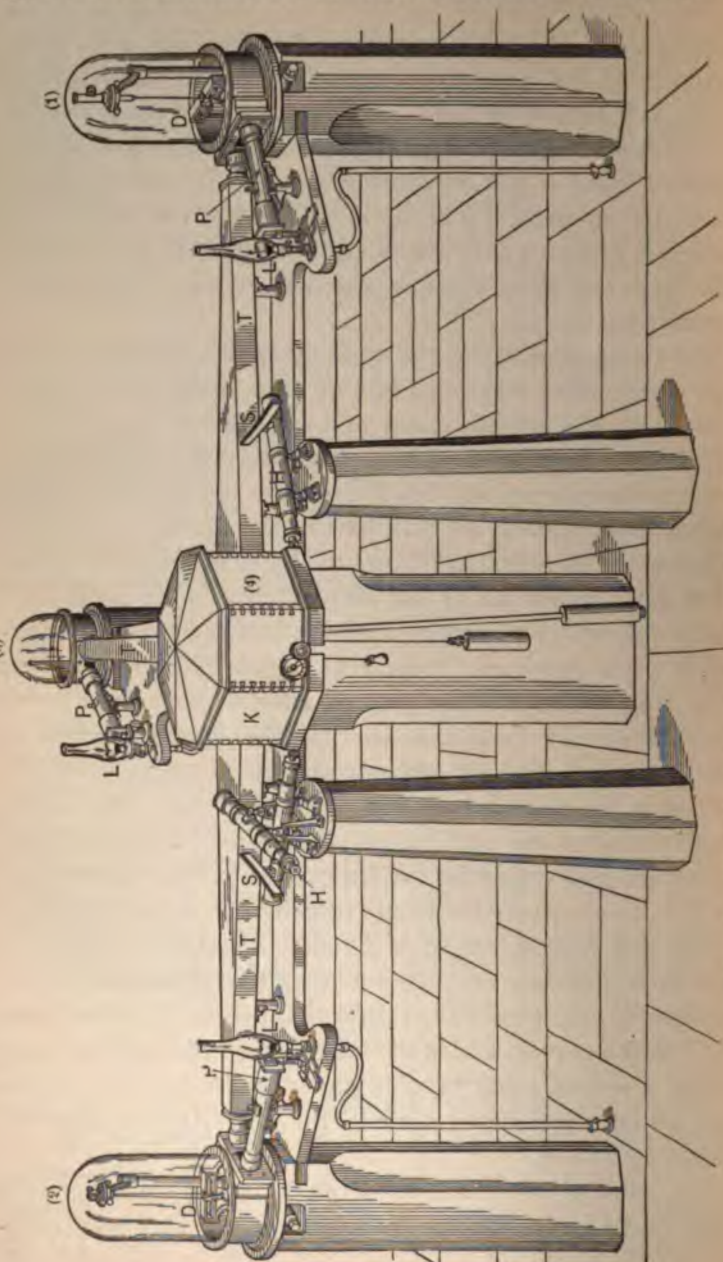


PLATE E.—GENERAL VIEW OF MAGNETOGRAPHS MOUNTED IN VAULT.

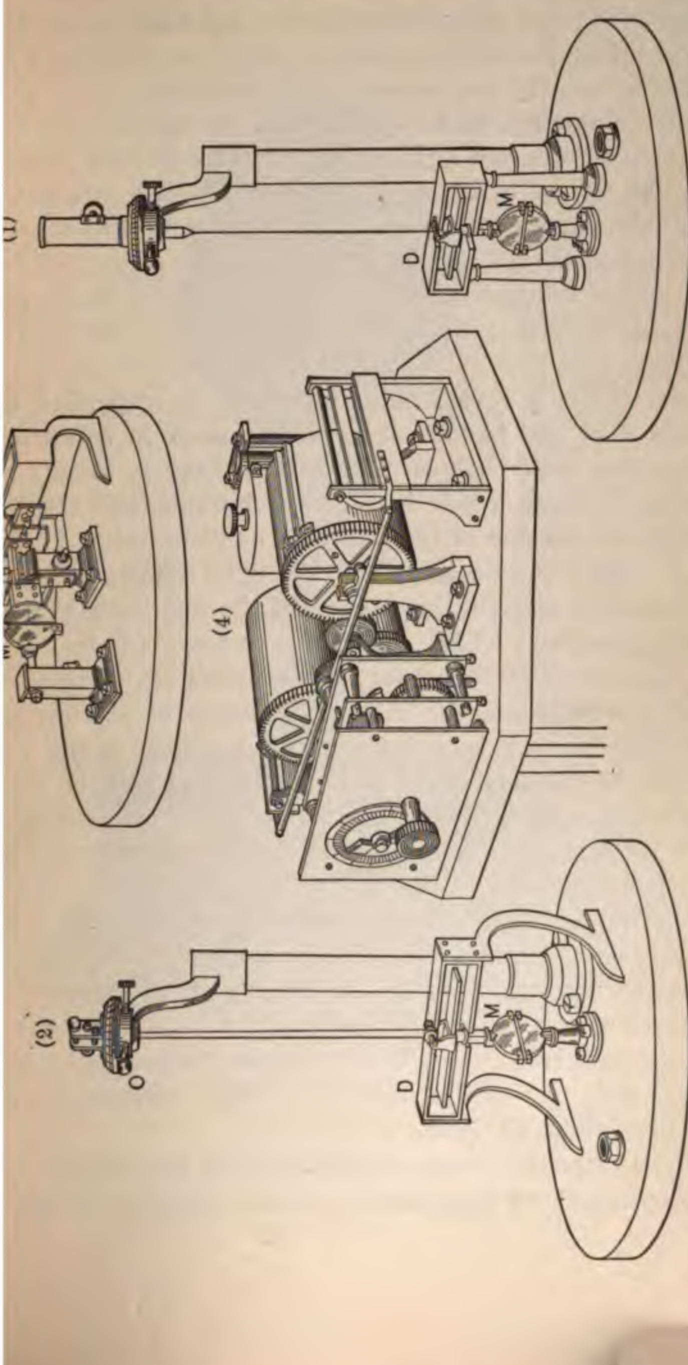


PLATE F.—ENLARGED VIEW OF APPARATUS (1), (2), (3), AND (4) OF PLATE E.

lation, time and temperature curves are also photographed upon them: thus side by side all the connected phenomena are continuously and automatically recorded.

If the magnet remains at rest and the roll of paper turns, the spot of reflected light imprints a trace at right angles to the axis of the revolving cylinder, which is a straight line when the paper is unfolded; if the cylinder remains quiet and the magnet moves, the line is parallel to the axis of the cylinder and of a length equal to the amplitude of the magnet's motion: if both cylinder and magnet move, the line is a zig-zag.

At (1) is the variation magnet: it is suspended by a single fiber and has freedom of movement in a horizontal plane; the upper half of the mirror is fixed to it by a stem passing through a hole in the copper frame, and the lower half to the bottom of the box with its plane set at a known angle with the true meridian; the light reflected from this half draws a straight line on one of the two horizontal rolls the base from which measurements are made to the zig-zag line traced by the upper half of the mirror. These measured distances are the relative positions of the magnetic meridian—in fact the relative successive values of the Variation at the times recorded beside them: to make these absolute values, all that is necessary is to compare any one of them with the Variation determined at the same time by the large variation magnet in Plate G.

At (2) is the horizontal intensity magnet: the suspension is by a fine steel wire that passes round the groove of a small wheel on top of the magnet, and then has both ends fastened at O to a horizontal screw, at a distance apart equal to the diameter of the wheel; thus the magnet is in reality suspended by two wires—the bifilar suspension—both equally tight at all times.

The suspension has such direction that the magnet is held approximately at right angles to the magnetic meridian—a

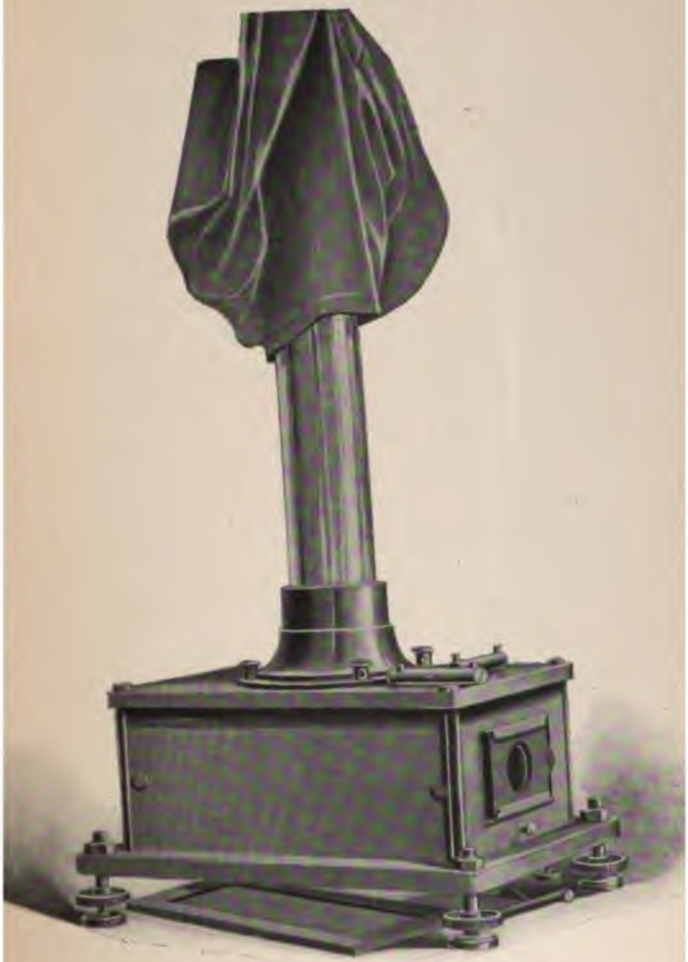


PLATE G.—LARGE VARIATION MAGNET.

sensitive, unstable position. The principle of this instrument is one that has already been described—the balancing of magnetism against another force. If a heavy beam be hung by two ropes, one near each end, it will settle into the vertical plane through the ropes; if the beam be forcibly turned round a vertical axis midway between the ropes, it will tend to return to its former position of rest with a force inversely proportional to the length of the ropes, and directly to their distance apart and directly also to the *sine* of the angle of deflection and to the weight of the beam: and this directive force, whatever one chooses to call it—gravity, or weight of the beam, twist of the ropes, or both combined—is precisely what acts on the steel bar of bifilar suspension to keep it across the meridian, while the Earth's horizontal intensity, acting on the magnetism of the same bar, tends to turn it parallel to the meridian. The balance of these two forces determines the direction of the magnetic bar, and so it will lie as long as they are equal. The weight of the bar, its magnetic moment, and the twisting force of the suspension wires or, briefly, the force of direction may (with proper corrections) be considered invariable; this all on one side of the balance: that on the other—the Earth's horizontal intensity is ever waxing and waning, and hence the position of equilibrium of the magnet is constantly changing, and the mirror attached to the magnet flashes these changes upon the roll of paper in (4) where they are photographed in a sinuous curve. Measured from the base line traced by the lower half of the mirror, these may be converted into absolute measure by comparison of any one of them with the intensity determined at the same time by oscillation and deflection experiments with the unifilar magnetometer.

At (3) is the vertical intensity magnet—a steel bar with a knife-edge axle that rests on agate rails and is provided with means of delicately and accurately balancing it in a horizontal position previous to magnetization and also after-

wards. The final adjustment is such that the center of gravity of the system is slightly below the center of suspension, the effect of which is, that the more the magnet is drawn down from a level position by the vertical magnetic intensity, the greater is the mechanical moment of the bar to bring it back: the latter is constant—the former variable, so that the continued balancing of the two makes the bar move up and down—a motion that is reflected by the mirror on the vertical roll of paper in (4) and there photographed as a serrated line.

Plate H is a reproduction from an actual photographic record for two days each of the Variation and the Horizontal Intensity. Sometimes these curves are quite even and regular, indicating a quiescent magnetic atmosphere; and again, when a magnetic storm is raging, of which an example will be given in the next chapter, they are serrated, jagged, and irregular in strict conformity to the violent, writhing condition of the magnetic medium. The straight lines at the bottom of the Plate are the base lines, with the hours of the day spaced along them.

Of late years, the records of magnetic observatories have been greatly vitiated by the proximity of electric street railways, and in some cases to such extent as to cause entire suspension of the records: the electromagnetic waves emanating from the operating current affect the instruments and mask the natural movements of the magnetic medium.

In Germany, objection has been made to electrical railways with overhead supply and rail return coming within a radius of fifteen kilometres of a magnetic observatory; and the delicacy of the instruments at the Potsdam Observatory is such that the influence of a cut-up continuous current has been detected at a distance of seventeen kilometres.

147. Instruments for absolute measurements.—The absolute instruments are to the curves of the magnetographs what the " mean sea-level " is to the rise and fall of the ocean

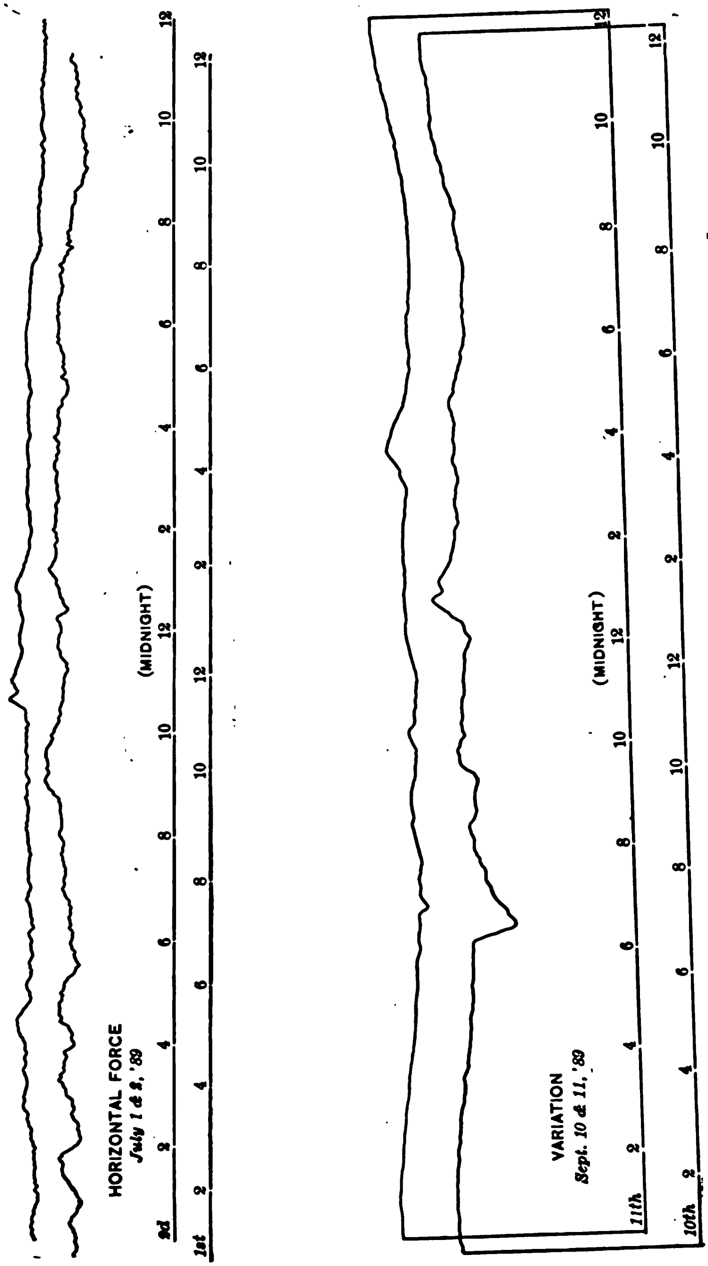


PLATE H.—PHOTOGRAPHIC RECORD OF THE MAGNETIC VARIATION AND HORIZONTAL INTENSITY.

recorded by automatic tide-gauges—a standard of reference. Periodically, observations are made directly: of the Variation with the instrument shown in Plate G; of the Dip with the Barrow Circle; and of the Horizontal Intensity with the Kew Unifilar Magnetometer. The Dip is not recorded graphically—but observed, and also calculated by the following formula from simultaneous values of the horizontal and vertical intensity given by the magnetograph curves,

$$\tan D = \frac{Z}{H}. \qquad (80)$$

The Total Intensity is neither observed nor graphically recorded, but calculated from simultaneous values of the horizontal and vertical intensity given by the magnetograph curves, by this formula,

$$T = \sqrt{H^2 + Z^2}. \qquad (81)$$

As stated previously, one point of the curve of Variation or Intensity being fixed in absolute measure by direct comparison with a determination of the same element at the same time by an absolute instrument, all other parts of the curve —at hourly intervals, for instance—become readily convertible into absolute measure; and this is the way in which tables of the elements are made up.

Methods of determining the Dip and Intensity have been given in previous articles: it only remains to describe the absolute variation instrument of Plate G.

The magnet is a rectangular bar, 12 inches by 1.25 inches by 0.2 inch—suspended by silken fibers fastened to a torsion circle at the top of a thick glass tube 60 inches long; the magnet has sliding weights and small levels for adjusting it to horizontality, and it swings in a brass box with glass ends. At the middle point of the magnet there is a metal strap with two studs for suspension points—one above, the other below,

so that the magnet may be turned for observations erect and inverted to correct for irregularity of magnetic axis. A pure copper frame surrounds it to reduce and steady its movement; and a small mirror with screws for accurate adjustment is attached to its south end.

The theodolite for observing the magnet is mounted on a brass block which travels east and west by means of a large screw, on rails embedded in another block of brass secured to the top of the pier: the pier is some distance from the magnet. The horizontal circle of the theodolite is 10 inches diameter and can be read to seconds by two micrometers. On the north side of the theodolite pier, just above the floor, is a curved scale, of radius equal to its distance from the suspension thread: the scale has adjusting screws and levels. From the frame of the theodolite a plumb bob is suspended so as to hang in front of the object-glass of the telescope, the point of suspension having a small lateral motion by means of a screw.

To determine the Variation with this instrument, a number of adjustments and corrections have to be made preliminary to the chief work, which consists of two parts: 1st, to determine the reading of the horizontal circle of the theodolite corresponding to the true meridian; and 2d, a similar reading for the magnetic meridian; the difference of the two is the Variation at the instant of observation of the magnetic meridian.

The true meridian is found from transits of the stars, and the magnetic meridian by observing the scale divisions reflected by the magnet mirror across the vertical wire of the eye-piece of the telescope as it oscillates to and fro, and taking the mean of a sufficient number each way to give an accurate result, the reading of the horizontal circle of the theodolite corresponding to this mean being the required direction of the magnetic meridian.

CHAPTER IX.

SUN-SPOTS; AURORAS; ELECTRIC DISCHARGES IN HIGH VACUA; MAGNETIC STORMS; AND TELLURIC CURRENTS.

Section One: Sun-spots—Their Aspect, Motion, Lifetime, Spectrum, Periodicity, and Cause.

148. The Spectroscope.—The phenomena treated in this Chapter have received such elucidation from researches with the spectroscope and the application of Doppler's Principle, that a brief description of both, preliminary to the main subject, seems desirable.

The spectroscope has a variety of forms, but the *principle* of all may be illustrated by Fig. 193: it consists of three parts,

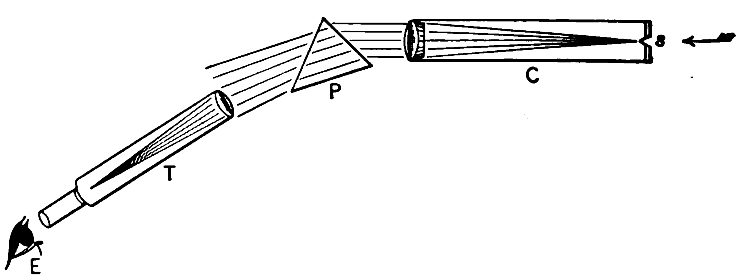


FIG. 193.

the collimator C for directing light from a source; the prism P for decomposing it; and the telescope T for examining in detail the spectrum thus formed. The light enters the aperture s and emerges in parallel rays from the lens A, thence

following the course indicated, to the eye. The aperture may be of any form, but a narrow slit of variable width is the usual one—it admits a *line* of light. Suppose this to be a single color—red; it has a definite refrangibility, and therefore, after traversing the prism, will appear to the eye at a certain point as a narrow line, which is the exact size of the slit.

Let the light be orange—a mixture of red and yellow: these colors have different refrangibility, the prism will separate them, and the eye will perceive two narrow lines—one red, the other yellow, with a space between. Let the light be composed of many colors—then the prism will assign to each the exact point its refrangibility requires, and the eye will see a corresponding number of variegated lines spaced apart like the pickets of a fence. If, however, the light be that of a candle, composed of all shades of every color, then each will, as before, be refracted to its proper point, but they pass by such insensible gradation one into another, that they blend into a continuous ribbon of every hue.

Each shade of every color has a specific wave-length—so many ten-millionths of a millimetre (the unit being one ten-millionth), by which it is designated: thus, a particular shade of incandescent hydrogen is known as λ 3970.2, meaning thereby that this wave-length λ is 3970.2 ten-millionths of a millimetre.

If any wave-length or shade of color be specially abundant in a sheaf of rays, its line or place in the spectrum will be more brilliant than the others; and if any be wholly absent, its line will be dark: the entire solar spectrum is crossed by dark lines, showing that certain shades of color or wave-lengths, originally proceeding from the photosphere, are absorbed by the reversing layer, or envelope of comparatively cooler gas, that lies above and about the self-luminous clouds composing the solar disc. It is not the prismatic colors alone that form the spectrum of the Sun, but there is a great range of ultra-violet rays that only photographic

Sun makes a full revolution. The average lifetime is two to three months, and the longest yet known was eighteen months. They seldom come singly, but in groups.

There is no regular process of formation of a spot—it is both gradual and rapid—sometimes the work of a day, and again of weeks: a disturbance becomes manifest by the appearance of minute black dots; these enlarge, with grayish patches between, as if a dark mass lay screened below a thin stratum of luminous filaments; the veil grows thinner and vanishes, disclosing the completed spot.

When its end approaches, the surrounding photosphere seems to crowd in upon the penumbra, bridges of dazzling light push across the umbra, the penumbral filaments become confused, and the luminous matter seems to tumble pell-mell into the chasm: the agitation gradually subsides and the spot is gone. At times, though very rarely, a different phenomenon of the most startling character appears with spots: patches of intense brightness suddenly break out, remain visible a few minutes, and move with a velocity as great as one hundred miles *a second*.

" In a few instances these gaseous eruptions near a spot are so powerful and brilliant that with the spectroscope their forms can be made out on the background of the solar surface in the same way that the prominences are seen at the edge of the Sun. In fact, there is probably no difference at all in the phenomena, except that only prominences of most unusual brightness can thus be detected on the solar surface. An occurrence of this kind fell under my [Prof. C. A. Young's] observation on Sept. 28, 1870. A large spot showed in the spectrum of its umbra all the lines of hydrogen, magnesium, sodium, and some others, *reversed*.

" Suddenly, the hydrogen lines grew greatly brighter, so that on opening the slit of the spectroscope, two immense luminous clouds could be made out, one of them nearly 130,000 miles in length by some 20,000 miles in width, the other

about half as long. They seemed to issue at one extremity from two points near the edge of the penumbra of the sun-spot, remained visible about twenty minutes and then faded gradually away." The protuberances are most numerous in the solar latitudes precisely where the spots are most abundant, but they do not cease in lat. 40°, as the spots do.

Besides moving *with* the mass of the Sun, the spots themselves move *along* its surface; and they are practically confined to two belts, one on each side of the Sun's equator, between latitudes 10° and 35°. By the motion of the spots the time of revolution of the Sun has been determined: but it has no *one* definite period as the Earth has; equatorial regions complete a revolution in less than 25 days; the zone of latitude 20° in about $25\frac{3}{4}$ days; that of 30°, in $26\frac{1}{2}$ days; and of lat. 45° in $27\frac{1}{2}$: this is another feature confirmatory of the Sun being a gaseous body, for no solid mass could have such a variable time of revolution of its different parts.

"The spectrum of a spot tends to show that the dark portion is a cavity filled with gases and vapors which produce the obscuration, in part at least, by absorbing the light emitted from the floor of the depression. At times, the spectrum of a spot gives evidence of violent motion in the overlying gases, by distortion and displacement of the lines. In such cases it often happens that lines side by side are affected in entirely different ways—one will be greatly displaced while its neighbor is not disturbed in the least, showing that the vapors which produce the lines are at different levels, and do not participate to any great extent in each other's movements." (Prof. C. A. Young.)

Between 1825 and 1851 the face of the Sun was closely watched every day and a complete record obtained of the spots appearing during that time: it disclosed the unexpected fact that there is a periodicity of maxima and minima in the number of the spots.

Then the record of every spot for years was ferreted out

of its dusty abode, all were systematically classified, and the result—given in Table 22—confirmed not only the fact of

TABLE 22.

YEARS OF MAXIMA AND MINIMA OF SUN-SPOTS, AND RELATIVE NUMBERS INDICATIVE OF THE FREQUENCY OF SPOTS IN THOSE YEARS.

Years of Minima.	Years of Maxima.	Relative Numbers.	Years of Minima.	Years of Maxima.	Relative Numbers.
1610			1755	....	10
	1615			1761	86
1619			1766	....	11
	1626			1769	106
1634			1775	....	7
	1639			1778	154
1645			1784	....	10
	1649			1787	132
1655			1798	....	4
	1660			1804	73
1666			1810	....	0
	1675			1816	46
1679			1823	....	2
	1685			1830	71
1689			1833	....	8
	1693			1837	138
1698			1843	....	11
	1705	49		1848	124
1712	....	0	1856	....	4
	1718	51		1860	96
1723	....	10	1867	....	7
	1727	90		1870	139
1733	....	5	1878	....	3
	1730	83		1883	64
1744	....	5	1889	....	6
	1750	83			

periodicity already stated, but changed its time only slightly: the mean value is eleven and one-ninth years, with some variability on account of difficulty in fixing the dates of the largest and smallest number of spots.

Besides this mere alternation of varying number, another fact was brought out by the Table, namely, "that the interval from a minimum to the next following maximum is only about 4.5 years on the average, while from the maximum

to the next following mimimum the interval is 6.6 years"—that is, "the disturbance which produces the spot springs up suddenly, but dies away gradually." (Prof. Young.)

Of the many theories that endeavor to account for sun-spots, the following by Prof. Young seems to me to appeal most to the reason: "that they are depressions in the photospheric level caused, not directly by the pressure of the erupted materials from above, but by the diminution of upward pressure from below, in consequence of eruptions in the neighborhood: the spots thus being, so to speak, sinks in the photosphere.

"Undoubtedly the photosphere is not a strictly continuous shell or crust, but it is heavy as compared with the uncondensed vapors in which it lies, just as a rain-cloud in our terrestrial atmosphere is heavier than the air, and it is probably continuous enough to have its upper level affected by any diminution of pressure below.

"The gaseous mass below the photosphere supports its weight and that of the products of condensation which must always be descending in an inconceivable rain and snow of molten and crystallized material.

"To all intents and purposes, though nothing but a layer of clouds, the photosphere thus forms a constricting shell, and the gases beneath are imprisoned and compressed.

"Moreover, at a high temperature the viscosity of gases is vastly increased, so that quite probably the matter of the solar nucleus resembles pitch or tar in its consistency more than what we usually think of as a gas. Consequently, any sudden diminution of pressure would propagate itself gradually from the point where it occurred.

"Whenever a free outlet is obtained through the photosphere at any point, thus decreasing the inward pressure, the result would be the sinking of a portion of the photosphere somewhere in the immediate neighborhood to restore the equilibrium; and if the eruption were kept up for any

of its dust[illegible]
result—g[illegible]

YEARS OF [illegible] TIVE [illegible] SPOTS
Years of Minima
1610
1619
1634
1645
1655
1666
1679
1689
1698
1712
1723
1733
1744

[illegible] Spectrum, [illegible] Periodicity.

period[illegible]
the me[illegible]
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est and [illegible] green-
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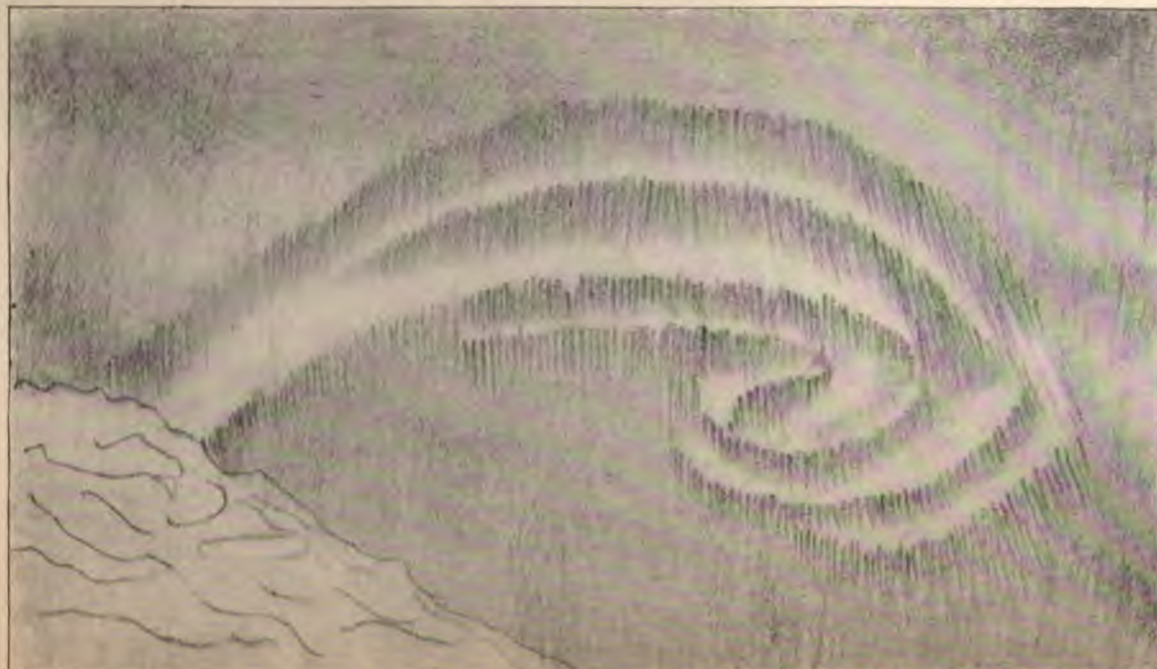

Fig. 191.

length of time, the depression in the photosphere would continue till the eruption ceased. This depression, filled with the overlying gases, would constitute a spot. Moreover, the line of fracture, if we may call it so, at the edges of the sink would be a region of weakness in the photosphere, so that we should expect a series of eruptions all around the spot. For a time the disturbance, therefore, would grow, and the spot would enlarge and deepen until, in spite of the viscosity of the internal gases, the equilibrium of pressure was gradually restored beneath. So far as we know the spectroscopic and visual phenomena, none of them contradict this hypothesis." No satisfactory explanation has ever been given of the regular periodical variation in number of the sun-spots.

Section Two: Auroras—Their Varieties, Colors, Spectrum, Extent of Visibility, Height above Earth, Periodicity, and Theory.

151. **Auroral forms and hues.**—There are many luminous conditions of the sky in polar regions, both austral and boreal, from the mere diffused light without rays, to forms of definite shape—arches like rainbows; streamers converging to a crown; draperies like flags floating in the breeze; and fan-shaped radiations: all are called auroras, and the summits of every kind are either in the magnetic meridian, or not far from it, while the beams are generally parallel to the direction of the dipping-needle.

Auroras are often of the most brilliant colors—crimson toward the lower contour, yellow in the middle, and greenish blue above—all soft and delicate tints.

So gauzy is their substance that stars may be seen through them, and when undulating, as they often do for hours, the moving folds of color are most beautiful.

Fig. 104 represents a draped aurora.

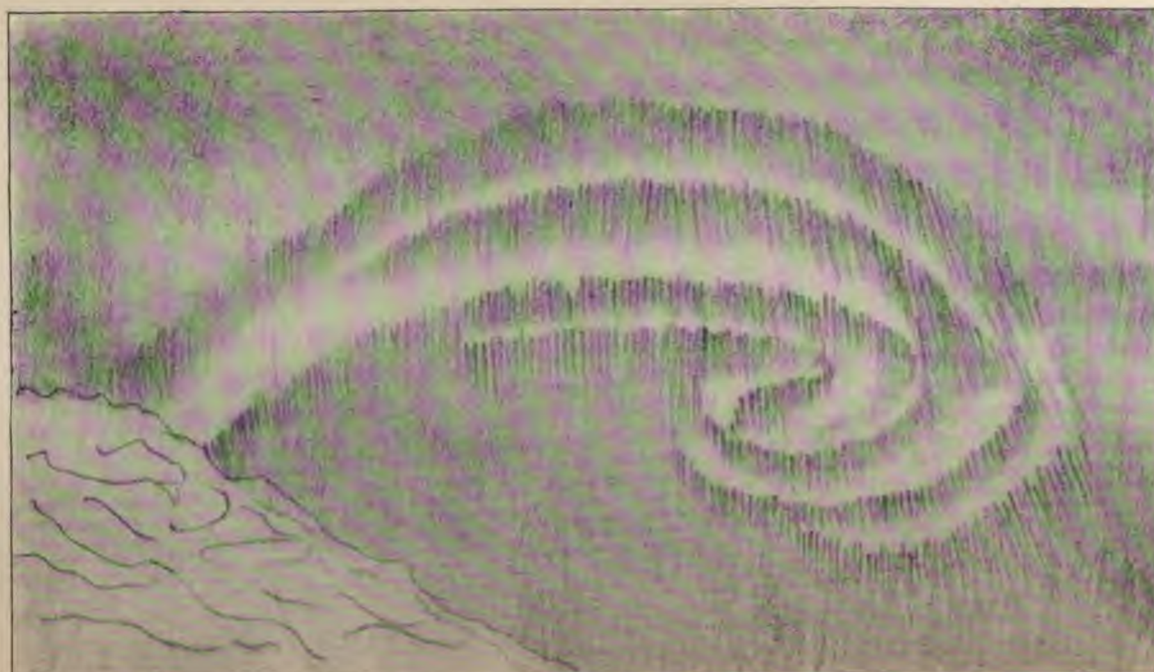

FIG. 194.

The duration of these phenomena varies from one to several hours, and the celebrated aurora of 1859 lasted more than a week.

152. Nature of the auroral light.—Auroras have been examined with polariscopes and spectroscopes.

Polarization is a condition of light-waves acquired by refraction through a substance, or reflection from its surface; and if light coming from a body exhibits this polarized condition, we know that it does not originate in the body.

Direct light from the Sun is not polarized—that from the moon is: the former is an original source—the latter a reflected one. There is not a trace of polarization in the auroral light, and hence it is self-luminous, and not as halos and rainbows are—phenomena of vapor reflections and refractions. And the spectroscope confirms this fact.

The spectrum of an incandescent body is an index both of its condition and chemical composition: solids, liquids and dense masses of non-transparent vapors give spectra composed of colors that merge one into another without break; tenuous gases, on the other hand, give spectra that resemble an irregularly spaced picket fence—the palings of different colors with dark gaps between; the particular colors and their spacing apart indicate the nature of the gas.

The spectrum of the aurora is of the latter kind, showing it to be due to a rarefied gas. To continue the metaphor, the pickets of this particular fence are yellow, green, and blue; that is, the wave-lengths of the auroral spectrum are in these colors, though one alone—the brightest of all—wavelength 557, of greenish-yellow hue, is absolutely characteristic of the aurora, not having been found in any other known body, except the zodiacal light.

The remaining wave-lengths or shades of color of the auroral spectrum are also found, either identically, or nearly so, in spectra of lightning and of electric discharges in very rarefied air.

153. Regions of auroral display.—Auroras increase rapidly in both number and brilliancy as we proceed toward the magnetic poles: indeed there seems to be two distinct classes of these phenomena—one, of restricted area, low in altitude, seen only in polar regions, and of little effect upon the magnetic needle; the other, high above the Earth, visible around both magnetic poles at the same time, like huge conical extinguishers that spread almost to the Tropics; and these are invariably accompanied by great magnetic disturbances, unusual telluric currents, telegraphic interruption, and solar outbursts and spots: in fact the whole electric and magnetic condition of Earth, Air, and Sun seems to be involved in one violent commotion.

The great aurora of 1859 was part of such a universal agitation: it consisted of numerous beams or columns nearly parallel everywhere to the dipping-needle, with its summit in the magnetic meridian. This aurora, by measurement, had its apex 534 miles, and its lower limit 46 miles, above the Earth—therefore, in the very rarest regions of the atmosphere, which would lend support to a previous statement that the electromagnetic waves arising from an outburst on the Sun, upon reaching the rare strata of our atmosphere, would illumine them as electric discharges do vacuum-tubes.

On the evening of Sept. 9th, 1898, an auroral display was visible in England, and on the following evening one was seen in New Zealand: "The whole southern heavens [in the words of an eye-witness] at first became suffused with a bright orange light low down upon the horizon, from which a few streamers issued from time to time, rising to a height of say 45°. When both glow and streamers had faded away, I noticed three luminous clouds, one at the zenith. The largest of these clouds increased in size, and shot forth a few streamers of light, both upward and downward, and all then disappeared. I have witnessed several auroral displays at Ashburton (New Zealand), but none like that of Sept. 10th,

the distinguishing features of which were the orange glow and the luminous clouds.

"On the following day, my telephone, which had never failed me before, worked irregularly, and some of the other telephones in the town were similarly affected."

More instances will be cited later of auroras having been seen at the same time in the most remote parts of the Earth. One observer finds an aurora "embodied in and swept the Earth with successive banks of Cape Breton fog. . . . In this fog-bank hung, as it were, a brilliant curtain of light with a wide fringe or flounce of maximum brilliancy along the bottom edge, the light fading upward along the curtain, but traceable to the very zenith, and the curtain stretching from the eastern horizon out at sea to the western horizon on the low hilltops. The curtain was evidently vertical, thin, straight, long enough to reach from one limit of the vision to the other, and floating broadside before the south wind toward the north. No reasoning could convince me that these were not elements of the phenomena, and moreover, that the lower edge of the bright fringe was more than 100 or 200 *yards* away at its nearest point when we first saw it. Its rate of departure from us was evidently that of the fog-bank or that of the gentle south wind then blowing.

"The perspective of the whole curtain changed in conformity with that supposition."

Another observer found an aurora so distinctly an entity of a clear blue sky that he obtained a photograph of a landscape by means of its light, which was vivid enough to obscure the stars.

And still again, an Arctic explorer of wide experience having fallen with his train into a deep rift between the ice and the shore, where the dogs tumbled about in the darkness and none could see what to do, when "suddenly from the summit of a neighboring cliff, an aurora of great beauty and power appeared in the southwest and shed upon us a

light so intense that we could see the smallest articles of our equipment, and were enabled thereby to extract the dogs from their tangled harness and proceed in safety. A severe snow-storm was raging and before the appearance of the aurora, the night was pitch dark."

Observations long continued in various parts of the globe establish the fact that daily, yearly, and secular maxima and minima occur in the number of auroras; and that even their most brilliant phases, undulating motion, and final disappearance are not matters of haphazard, but rather of regular recurrence.

All this periodicity is closely analagous to like periodicity in the ebb and flow of the magnetic medium pervading Earth and Air, as illustrated in the variability of the magnetic elements: it denotes some connection between the two kinds of phenomena, which will receive more support later on.

The *daily* maximum of auroras occurs in the early part of the night of each locality, and the minimum toward morning; the *annual* maxima take place in the spring and autumn proper to each hemisphere, and the minima in their winter and summer; but it is the *secular* periodicity that is of most interest and importance, as coinciding with that of another phenomenon—sun-spots—that has already been alluded to as (indirectly, at least) a possible cause of the auroras: that is, auroras are the glow of rarefied atmospheric regions due to the advent of an electromagnetic flux; this results from violent solar outbursts; these accompany sun-spots: and hence the grandeur and number of the heavenly illuminations should bear some correspondence with the size and frequency of the sun-spots—and they do. The connection is most striking, as will be seen by Fig. 195, where the upper curve represents the varying number of auroras and the lower curve that of sun-spots during a period of 150 years, from 1720 to 1870.

154. Theories of the Aurora.—It is but a natural step to offer other explanations of the aurora. Conceding—which is the fact—that the variation of any intense magnetic condition will illumine rarefied air within its influence, this illumination may also be brought about by electromagnetic waves issuing outward from the Earth when its magnetic equilibrium is greatly disturbed; and such disturbances would

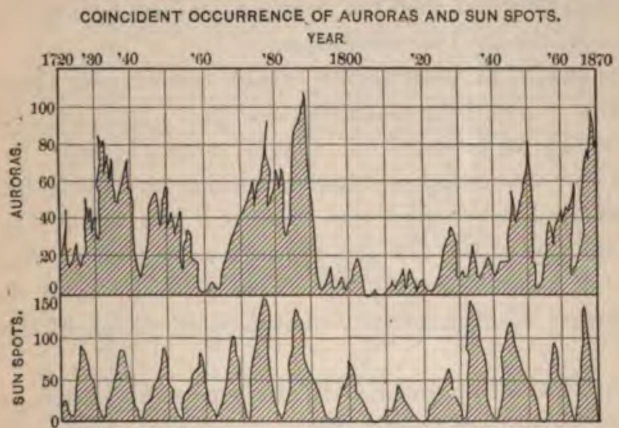

FIG. 195.

explain another fact observed during great auroras—the wild commotion of magnetic needles: both aurora and magnetic storm would then be the visible consequence of the same cause—a fluctuation of the Earth's magnetism.

The theory that the aurora is of electric origin rests chiefly on two facts: 1st, that its light resembles the glow of a vacuum-tube pervaded by an electric discharge; and 2d, that magnetic needles move erratically with the swaying of auroral beams, the darting forth of their rays, or the varying brilliancy of their colors—it amounts almost to a rhythmic movement of both aurora and needle.

Consider Plate J—a record of the magnetographs in the

U. S. Magnetic Observatory at Washington, February 13th and 14th, 1892: it is of special interest as showing the behavior of the instruments during an unusually severe magnetic storm which occurred simultaneously with fine auroras and a large group of sun-spots. The sharply serrated curve of Variation V, of Vertical Intensity Z, and of Horizontal Intensity H—all attest the most erratic movement of their respective magnets; the precipitous peaks and deep hollows are in marked contrast with the nearly even lines beside them, indicative of the normal condition.

The magnetic commotion began suddenly at 12.40 a.m., and while it lasted the Variation changed 1° 30′, the Horizontal Intensity 2½ per cent of its mean strength, and "the Vertical Force decreased so much that the sensitively balanced magnet used to record it was upset at 8 p.m. of the 13th, and its further record lost. The auroras were seen at Washington about 2 a.m. and 7.03 p.m. of the 13th, the latter time being marked by an unusually disturbed condition of the magnets."

Besides the Sun and Earth, already mentioned as possible sources of the electromagnetic condition of the air that may be productive of auroral phenomena, there is another source that has received some acceptance, namely, the evaporation from tropical seas. While it *may* be true that the *mere conversion* of the closely aggregated condition of particles, as water, into the loosely diffuse state, as vapor, does *not* give rise to electricity, still there is nothing more firmly established than that vapor *does* excite it, and of great power and volume *when it rubs against solid particles:* witness, for instance, the hydro-electric machines. And there is nothing more true than that our atmosphere is often heavily charged with electricity: it bursts forth in the vivid flash and crashing thunder-storms of tropical and temperate zones, but how is the tension relieved in frigid ones? Not in violence and destruction, but as a gentle, beautiful illumination of delicate

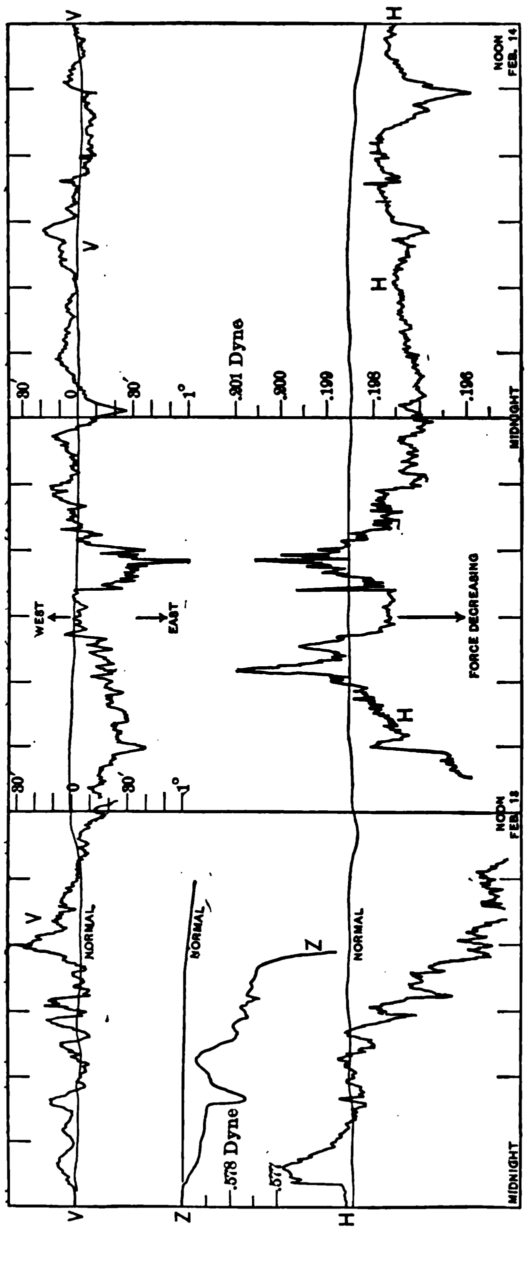

PLATE J.—RECORD OF MAGNETOGRAPHS DURING MAGNETIC STORM ACCOMPANIED BY AURORAS AND SUN-SPOTS.

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is occupied by the natural air at normal pressure. When the machine is in action, electricity escapes from the points *P*, but no illumination takes place in the space *A*—it gives no

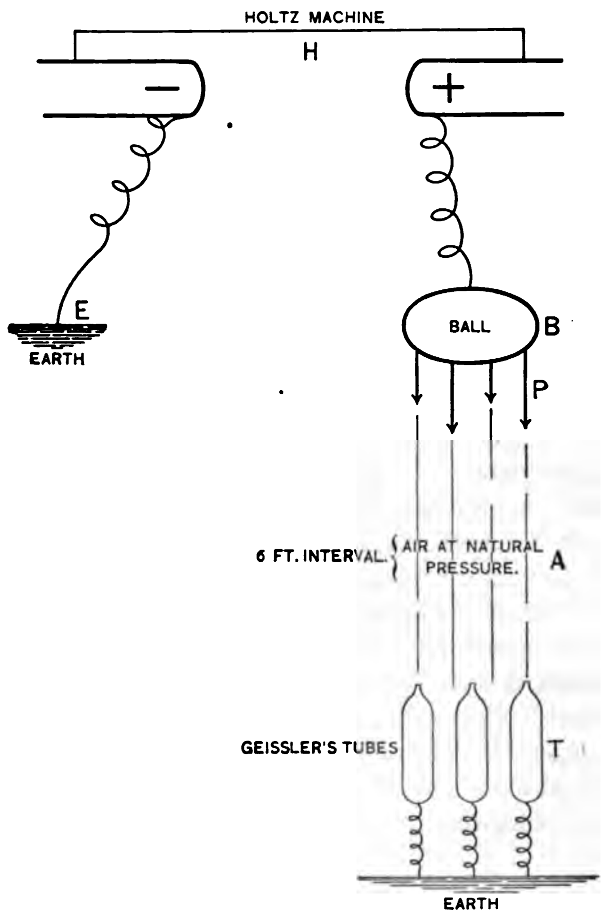

FIG. 196.

indication whatever that electromagnetic waves are passing through it; but there are, and upon reaching the tubes *T*, they light them up in a manner similar to the aurora.

tints—the slow escape of electricity, as in th
and St. Elmo's fire.

It is in the middle of the day; during t
year; and in *tropical zones*—both the tim
which the Sun's rays are most direct—th
est, and the light brightest, and chemical
solar energy most productive of result
tense: would it not be strange, then, if
netic phase alone of this energy lack
where all else was at its best? But it
it arises, its greatest force is spent in
its mild dissipation is reserved for po

The explanation usually given
decay, is the following: the particles
the upper currents of air waft them
they near these, they encounter cl
afford safe and easy conduit for th
The higher potential of upper
lieved in auroral displays, where
the medium because no lightni
course the discharge to Earth
sistance, which accounts for th
ible, the Earth's magnetism
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carrying an electric current
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An experiment made
auroral glow by electrical
196 may represent the ap
chine, one of whose po
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posts
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upon them,
feet apart;
with points
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line of the aurora,
parts of the sky. It
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already exists, and may
favorable. Twice, with
analogous to an auroral
the greenish-yellow
appeared during an
—Prof. Alfred Angot,

aurora, according to
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... and it seemed that electricity ...gin. this led to rarefied gases as an ... existence, and hence some feat- ... in vacuum-tubes will be described ...y a doubt that these phenomena are ...urora—the points of resemblance are ... intimate relationship.

...arge presents many phases of form, in- ...: it may be concentrated and destructive, ..., blinding in brilliancy or scarcely visible ...he giant induction-coil tears the air with a ...s long, ramified from a zig-zag stem, like the ...ree from a parent trunk; the terminals of a ...e, separated by a few centimetres, will give a ...r-cut, dazzling line; and the passing thunder- ...ently evoke around terrestrial objects a soft deli- –an electric halo.

...otential between points and the density of the me- the principal factors in determining the nature of ...harge: no violent effects can be produced by small ...ces of potential, any more than the rippling brook can ... great water-power; and on the other hand, high volt- ...nd great volume—like the fall of Niagara—means stu- ...ous results. So with the medium: its tenuity may so ...ly approach a perfect vacuum, or its density be so great, ... in either condition, no spark, however short, can be made pass by even the most powerful machines. The nature of ... medium, whether one kind of gas or another, and its ...mperature, together with many minor conditions, all in- ...uence the character of the discharge.

156. St. Elmo's fire.—When heavily charged thunder- clouds are passing over, they induce an electrical condition opposite to their own in salient objects; from these a slow discharge takes place with a bluish light and faint crackling sound: such manifestations are known as *corpo santo* and St.

Elmo's fire, and are seen on mast-heads, yard-arms, and even the hair, and tips of the fingers. Their form, noise, and luminosity are identical with the brush discharge from a spherical conductor of a Holtz machine in action; and the phenomenon is really due to a multitude of little sparks arising between the particles of air.

157. Auroral phenomenon experimentally produced.—By placing the brass socket of an incandescent lamp on the conductor of an electrical machine in action, the bulb becomes a reservoir of electricity: its whole interior glows like the body of a fire-fly—a soft and feeble radiance, which disappears upon removal from the conductor. But it lights up again and again upon touching the brass socket to the walls or furniture of a room. It is not the carbon that becomes a dazzling thread, as when the current is coursing through it—the filament may be broken—but it is the remaining particles of air left in the bulb after partial exhaustion, that are thrown into such vibration that they become radiant of themselves. In watching the fluctuations of the interior of such a bulb "as one's hand is moved over the glass, one is forcibly reminded of the streaming of the aurora borealis, and one cannot but conclude that the wavering light of this phenomenon is due to the same cause—the slow discharge through rarefied air of the electrical charge on the condenser formed by the upper layers of clouds and the lower strata of humid air." (Prof. Trowbridge.)

An experiment by de la Rive to simulate the phenomena of the aurora will now be described. Fig. 197 represents the apparatus used: *E* is an electromagnet from which wires *a* and *b* lead to a source of electricity; upon it rests a soft-iron cylinder *RF*, encased in a glass tube which tube is coated inside and out with shellac, thus insulating the cylinder, except at its ends *F* and *R*; a brass ring *C* encircles the lower part of the tube; an oval glass receiver *H* covers the cylinder *FR*, with means at the top for exhausting the air; the wire *k* from

the positive pole of a Holtz machine brings a current to the *lower* end of the soft-iron cylinder, and the wire *h* establishes connection between the negative pole and the brass ring. Before rendering the electromagnet *E* active, the Holtz machine is worked, and a delicate egg-shaped glow will at once

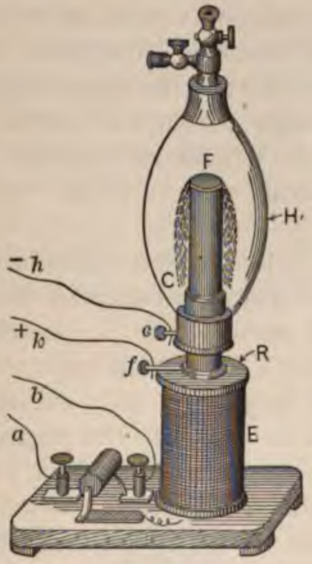


Fig. 197.

surround the soft-iron cylinder *FR*, presenting the aspect of a luminous stream issuing from the head *F*—permeated with brilliant streaks—and falling upon the brass ring *C* below. So far, the soft-iron cylinder seems merely an interior conduit for this exterior overflow—waves of electricity surging through it, out at the head, becoming luminous in the rarefied air of the enclosing vessel, and coursing toward the brass ring. But now send a current through the electromagnet *E*; this (by induction) makes a magnet also of the cylinder *FR*, and immediately this new condition becomes manifest by the luminous oval form turning round the cylin-

Elmo's fire, ... of the aurora turning the hair, ... —for these phenomena luminosity ... east to west as much as spherical ... phenomena ... ing betwee...

157. Au... ectrical flow.—It has been ... are bent by the Earth's ... its own lines—that such By placing ... ctors of electromagnetic conduct... ustrated by a vacuum-tube: comes a ... converts the remaining the body ... and that may be attracted, appears ... out, by a magnet waved again a...

or furn... luminous oval shape, formed dazzlin... ween the electrodes of a source the fila... a vacuum, it is mostly of of air ... solid particles entering it into ... ole, raised to incandescence. In ... the negative pole; it may be "a... ge, and an arc over eleven min... ed. Now such an arc is en- no... a magnet; it recedes or ap- is ... when the magnet is strong fie... a very powerful electromag- th... at right angles to the length of (P... e, drawing out to ten times its ... Earth's magnetism affects it: one of ... the arc vertical, it was 74 mm. a... was above, as against 56 mm. a... the electrodes are two soft-iron e... between them, it may be en- s... verting the electrodes them- a... rounding each with a helix and ... To establish the arc anew with ... they must be moved nearer

each other, and then the arc is changed in appearance: atoms are torn from the pole and projected in every direction with a hissing sound like escaping steam.

159. Character of discharge in rarefied gases. — By means of an induction-coil provided with different kinds of terminals and a suitable arrangement for varying the potential, we may produce three distinct phases of electrical discharge in air at *normal pressure:* the dazzling streak that darts from one pole to the other; the bright twig-like plume that spreads out from the rounded head of a conductor; or the hazy glow of a continuous escape from a single electrode. These, of more or less intensity and size, are all, however, that air or gas at normal density will admit; but where the tenuity is as great as the hundredth, the thousandth, or the millionth part of an atmosphere, then other and most marvelous forms of discharge appear.

FIG. 198.

The gradual transition in the nature and appearance of a discharge, as the medium becomes rarer, may be followed with the apparatus represented in Fig. 198: it consists of an egg-shaped glass receiver having a stuffing-box in the top

der *FR* as an axis. It is the parallel [illegible] this consti-
round the great magnet—the Earth [illegible] source of elec-
have been observed to move from [illegible] the bottom of
20° an hour. [illegible] are two stop-

158. Action of magnets on elec[illegible] the other with
stated that the auroral streamers [illegible]
magnetism into conformity with [illegible] discharge is the
beams appear as flexible cond[illegible] is worked the
waves: this phenomena may be il[illegible] upon drawing out
an electric discharge through [illegible] certain stage, the
motes of matter into a luminous [illegible] ball between the
repelled, or variously moved [illegible] the capacity of the
around the tube. [illegible] The luminous me-

Or again: the voltaic arc [illegible] examined with a spec-
by the passage of a current [illegible] spectrum will be ob-
of electricity. If produced [illegible]
ethereal construction, only [illegible] column becomes
as are torn from the posi[illegible] shapes of many
and hurled across the [illegible] alternately bright and
lengthened by increase[illegible] to the other. And
centimetres long has been [illegible] the most won-
tirely mobile under the [illegible] radiant state of matter.
proaches, and even [illegible] exhaustion that these
enough. In an experim[illegible] obtained. They are made
net, whose poles were [illegible] of the most fantastic
the arc, this darted [illegible] strikingly; and of every
normal length. Even [illegible] feet in length: platinum
experiment showed [illegible] for conveying the current
long when the pos[illegible] induction-coil—into their
when it was below [illegible] such tubes, with varied
rods, and the arc [illegible] curious entities that fill
tirely destroyed [illegible] exhaustion and electric
selves into magn[illegible] shape is that of an elongated
sending a current [illegible] luminous and drawn a little
these magnets [illegible]

from each other, leaving dark spaces between: their tint or color varies with the kind of gas pervading the tube.

By interposing an air-gap in the circuit, that is, cutting the conductor from the induction-coil just outside the electrode, and attaching a little ball to each cut end, so that they will be separated by a very short distance over which the current will have to leap as a spark—by doing this, the column of *striæ* becomes sensitive to the finger or any other conductor that affords relief to the strained state in and around it.

The whole phenomenon of sensitiveness is characterized by periodicity: the alternation of luminous disk and dark band simulates well the crest and trough of a wave or pulse of electricity emanating from each electrode; a telephone in circuit proves their periodicity, for it gives a musical note—that due to the number of pulses per second, and the pulse or discharge may take place from one pole or both, equally, independently, or in any degree of inequality, and perhaps variously *interfere* and thus produce the wave effect. The discharge is not simultaneous along the tube, but progressive, and "each terminal pours forth its electricity to satisfy its own needs, and only in a very secondary degree to satisfy the needs of the other terminal."

Experiment leads to the conclusion that all discharges in rarefied gases are discontinuous, or of the nature of pulses—*waves*—whether artificially produced by an air-spark or not; for the fact that *striæ* are formed, lends support to such a view.

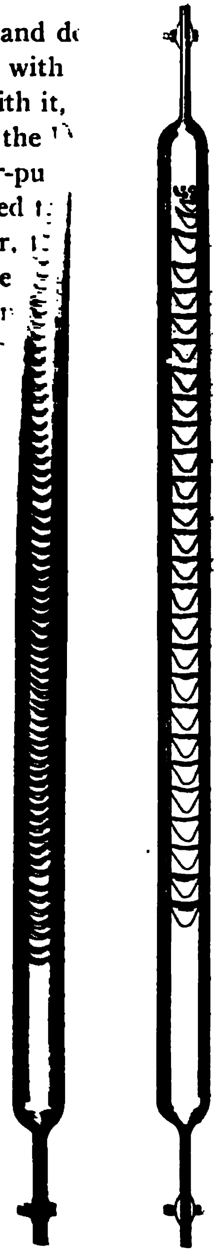
The *striæ* appear stationary at times, and at others as a continuous flow, or a flow both ways, backward and forward.

Lines of *striæ* are acted upon by a magnet—attracted, repelled, and moved about—just as a wire is that carries a current; only, that while the wire moves as a whole, the stratified column has all the mobility of its perfectly flexible nature; even more, each *stria* is subject to varied deformation under

through which a metal rod moves up and d
tutes one electrode in communication with
tricity, the other being fixed in line with it,
the vessel and connected to Earth; at the
cocks, one communicating with an air-pu
a reservoir of any gas it may be desired t

At normal pressure in the receiver, t
same as in the exterior air; but as the
sparks become straight, fuzzy, and lo
the upper rod. When the rarity reac
discharge appears like a glowing ga
electrodes, and this may be expande
receiver by continuing the exhaust
dium is then in such condition that
troscope, its own distinctive colo
tained.

With still greater tenuity th
stratified with marvelous and
kinds, as if a succession of w
dark, were flowing from one
when the highest vacuum poss
derful of all phenomena appea
But it is with *tubes* at various
several phases of discharge ar
of glass, generally straight, l
forms to bring out the effe
size, from a few inches t
electrodes are fuzed into t
from some source—ge
interior. Fig. 199 re
striæ—some of the n
them according to
power; but the most
pine-cone whose se



..s if it were an entity by itself, as well ..ction of a vertebral column.

... ..atter.—According to the dynamical the- ... ..cules of matter in its three states are con- ... and in the gaseous state, they have, in ad- ... ..ry movement—flitting hither and thither— ... ..sion with each other and with the walls of ... vessel.

.. of the gas is removed, the remainder has ... ..m of motion, and when only a few atoms are ... such free path that they scarcely meet or col- ... directly to and fro between the sides of their ... ..h, substantially, is the individualized condition of .. vacuum attained by Prof. Crookes in one of his ..re the pressure was only the $\frac{1}{20,000,000}$th of an atmos- ..ual to about the one-hundredth of an *inch* in a ..f mercury three *miles* high; and it is in this condition ..atter exhibits the properties called *radiant*. Before ..ng it, however—while there is still an appreciable pres- ..ay the thousandth of an atmosphere—the tube presents ..hase of luminosity and stratification already described;

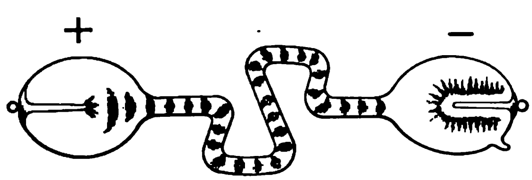


FIG. 200.

..is phenomenon apparently depends more on the *positive* ..an on the negative pole: it is shown in Fig. 200, which is ..ne of the fantastic forms of tube.

Here it will be perceived that around the negative elec- trode there is a narrow dark space and outside it a radial aureole, while at the positive pole a single bright star tips its

point; in close proximity to this the luminous *striæ* begin and extend through the serpentine neck joining the bulbs.

If the gas be nitrogen, the aureole is violet and the luminosity elsewhere of a rosy tint; if hydrogen, the colors are blue and crimson; if carbonic acid, the light is unusually white; and if oxygen, the contrast of shades is not very great. Now these gases are all in a rare state in the tubes; they are also in a rare state in the regions of our atmosphere where the polar auroras appear; the same colors are found in both phenomena; they are produced by electromagnetic waves coursing through the tubes—may not such also be their origin in the atmosphere, as heretofore stated?

When the exhaustion is carried to its highest stage, the aureole disappears, the luminous *striæ* fade away, and darkness spreads out from the *negative* pole, as if *this* were now the source of the changed condition pervading the tube.

A stream of electrified molecules pour out *normally* from the *negative* pole—they neither collide nor meet with obstacle in their path—and so proceed on through darkness to the glass boundary which they light up with beautiful phosphorescent and fluorescent effects. If gem or jewel—ruby, diamond or sapphire—be placed in their direct course, they will blaze with a brilliance never seen in other conditions. But if a sheet of mica, cut to any contour, be interposed, it arrests their flow, becomes electrified itself, and casts its exact shadow on the glass. The bombardment of the sides of the vessel produces a sound whose pitch is that proper to the intermittence in the current, by the air-gap.

A little wind-mill in their path will be set in motion; wherever they strike, heat will be generated; and their direct course may be bent in any way by a magnet. The sound, the heat, the phosphorescent glow, even the mechanical movement are all beautiful illustrations of the varied transmutations of electrical energy into vibratory, undulatory, and translatory motion of such nature as to affect our senses.

While it is true that the molecules of gas remaining in the tube produce these effects, still there must be waves—a propagation of *motion*, resulting from the discharge; for vacuum-tubes will light up and glow without any internal electrodes, or when merely brought within the confines of a changing electrical field: and also, the molecular discharge will not pass through glass, mica, or any transparent substance, whereas, if a *metal* window, say of aluminum, be inserted in a tube, the *effects* of the discharge in it can pass through such window and be experienced in the outer air where the phenomenon cannot at all be originated. Now it is inconceivable that the electrified *particles* of the gas pass through the *metal* window, so that it must be *motion* that is transmitted, as sound is through a wall, and this motion must have arisen concurrently with the discharge of the atoms of gas from the negative pole. It is another point in favor of the general view taken in this Treatise—that electricity is due to motion, as heat and light are—to a wave of the ether.

The corpuscles thus charged with electricity—radiant matter, as they are called—will not turn a corner: this is shown by means of a V-shaped tube having a pole at each upper extremity; when the discharge is from the negative pole of the right-hand branch, this is flooded with green light which stops short at the apex and will not enter the left arm; and when the current is reversed, the left arm which now has the negative pole, grows luminous, while the right remains dark. This property of movement in straight lines, as well as the effect of pressure of gas on the course of the discharge, is further illustrated by Fig. 201: the two vessels are identical in size, form, and arrangement of electrodes; in one, marked *A*, the pressure is equal to a few millimetres of mercury, and in the other, *B*, only the millionth of an atmosphere; in the first, luminous bands appear—in the last, only radiant phenomena; in the first, *A*, a line of violet light issues from the negative pole (—) and bends toward the posi-

tive pole, wherever that may be—at the top, bottom, or side; while in the last, *B*, the radiant matter is shot directly out from every part of the saucer-shaped negative pole, and con-

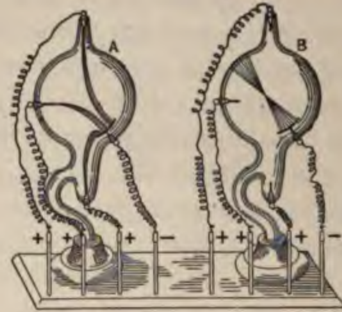


FIG. 201.

tinues straight on to the opposite side of the glass, regardless of the position of the positive pole.

That an obstacle in its path should cast a shadow is a direct consequence of this fact, which may be explicitly stated thus: that "radiant matter comes from the pole in straight lines and does not merely permeate all parts of the tube and fill it with light, as would be the case were the exhaustion less good."

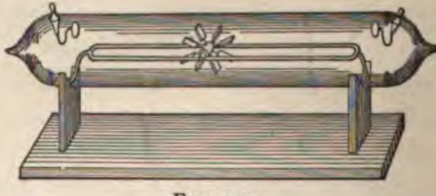


FIG. 202.

To show the ability of radiant matter to produce mechanical motion, the tube represented in Fig. 202 is used: its essential feature is a little glass railway upon which a light wheel rolls; the poles are so placed that whichever one is made negative, the particles of matter dart from it and strike

the mica paddles, causing the wheel to travel along the rails; by reversing the poles, the wheel is stopped and sent the other way; and if the tube be gently inclined, the wheel is actually driven up-hill.

This is the outward stream, but there is a return—of positively charged motes—as may be proven by drawing the little railway out of the direct flow, toward the walls of the tube, when the wheel will roll in the opposite direction under the influence of a counter-current.

To form the direct stream, the particles individually come in contact with the negative electrode, become charged with its electricity, and are thereby shot off—repelled from its

FIG. 203.

surface: like the projectile from a gun, they should cause recoil in the electrode—if moveable—and they do. Fig. 203 shows the means by which it is accomplished: it consists of a fly-wheel formed of four radii with aluminum disks coated on one side with mica; it is pivoted on a steel point that has metallic communication through the lower part of the vessel with an induction-coil, so that the moveable fly-wheel thus becomes the negative pole, the positive being in the top of

the vessel. When the pressure equals that of a few millimetres of mercury, and with the coil in action, "a halo of velvety violet light forms on the metallic side of the vanes, the mica sides remaining dark": as the pressure lessens, a dark space separates the violet halo from the metal—it enlarges and rotation of the wheel begins; the darkness reaches the glass and the rotation becomes very rapid.

A magnet has complete sway over a band of radiant matter, whether in moderately high or very high vacua. In Fig. 204 a line of phosphorescent light issues from the pole into

FIG. 204.

the highest vacuum and would proceed straight on, but is drawn down by a powerful magnet and waved about like a flexible wand as the magnet is moved to and fro.

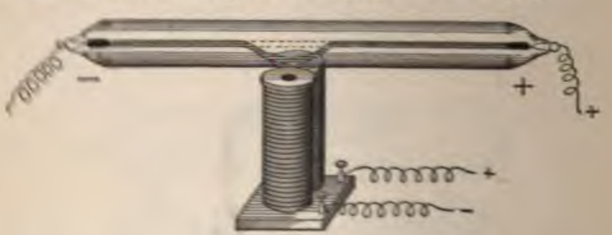


FIG. 205.

In Fig. 205 the vacuum is moderately high, and the line of violet light extends from end to end of the tube, with a bend downward to a magnet pole, which, however, would be upward if the other pole were presented.

The difference between the two cases illustrated by Figs. 204 and 205 should be noted: in the former, the radiant

stream continues in its *deflected* direction—in the latter, it rises and pursues the straight line again: this is due to difference of vacua. Indeed the action of a magnet on this luminous electric discharge is so decided that it facilitates the discharge when this is parallel to the lines of magnetic force, but retards it when at right angles thereto.

Fig. 206 beautifully illustrates magnetic action upon this

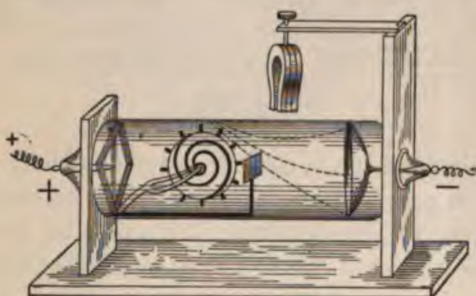


FIG. 206.

line of apparently intangible light, which, however, behaves as if made up of glowing pellets of *iron:* a light paddle-wheel is delicately supported by its axle in sockets, and protected by a screen from the direct course of the radiant stream; when one pole of a magnet is brought down upon the tube, it attracts the stream which strikes the paddles and causes rapid rotation as of an overshot wheel; when the other pole is presented, the stream is repelled, and there is rotation as of an undershot wheel.

In order to determine whether these beams extending in moderately high vacua from pole to pole are of the nature of wires carrying currents, or merely built up of electrified particles, the experiment illustrated by Fig. 207 is performed: there are two negative terminals *a* and *b* fuzed into one end of the tube and one positive terminal into the other end.

This enables either two streams to be sent side by side, or only one, by severing one of the negative connections.

If the streams carry an *electric current* they will behave

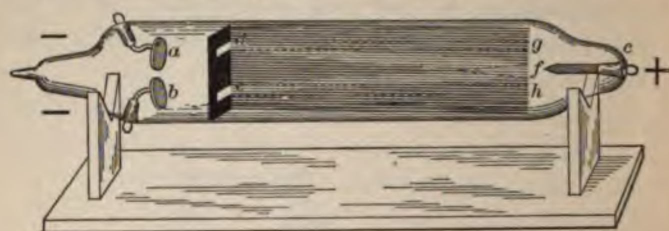


FIG. 207.

like wires doing the same, and attract each other; but if they are simply composed of *negatively electrified particles*, they will mutually repel. "The upper negative pole, *a*, was first connected to the coil, and the ray was seen shooting along the line *df*; the lower negative pole, *b*, was then brought into play, and another line *eh* darted along: instantly, the first line sprang up from its first position *df* to *dg*, showing that it was repelled, and the lower line was deflected downward." There was mutual repulsion of the beams, and therefore they are built up of similarly electrified particles.

If stopped in their flight, the motion of translation of these particles, like that of a cannon-ball, is converted into vibratory motion both of themselves and of the particles at the point of impact, and the result is intense heat. This is shown by Fig. 208: the negative pole consists of a spherical shell such that lines drawn normally from its interior surface converge to a point at the middle of the glass bulb, where a piece of iridio-platinum is supported by a wire.

By turning on the induction-coil slightly, the electrified particles shower from all parts of the negative polar shell into its focus, raising the metal there to a white heat.

On approaching a magnet to this concentrated fire, it will draw it aside, or spread it out, or drive it down so that

the metal is no longer luminous. Withdrawing the magnet entirely, however, the bombardment is again directed upon

FIG. 208.

the metal and it becomes white hot; and now on increasing the current, the iridio-platinum glows with almost insupportable brilliancy, and finally melts. All the preceding experiments on radiant matter are due to Prof. Crookes, quoted in Gordon's Electricity and Magnetism.

But the phenomena of electrical discharges in rarefied gas lead to a much more important goal than their similitude to auroral tints, which was the chief object of this section: they lead, in the cathode rays, to a consideration of the ultimate condition of matter. These rays are either waves in the ether—mere motion—or they are composed of material particles; and the experiments just described indicate that they are both—particles, while coursing through the tube from the cathode, and waves outside the aluminum window

[illegible] upon which they beat and produce the motion [illegible] as waves of ether, just as a heavy body [illegible] rise to waves of air around it.

[illegible] the cathode ray are conceived to be the [illegible] of matter to which the name *ions* is [illegible]. They are not atoms of the particular gas pervading [illegible] exhaustion, but matter in more minute [illegible]—smaller even than the atoms of hydrogen; and [illegible] with a definite quantity of electricity, which, [illegible] not the same for all, so that there are varieties [illegible] among the *ions*.

[illegible], it is conceived that the chemical elements [illegible] of these *ions*, and that the difference in the ele- [illegible] properties of zinc, mercury and oxy- [illegible]—arises from varied number and grouping [illegible] *ions*.

[illegible] trend of present thought, based chiefly on the [illegible] Analysis, as set forth in a former section [illegible]

[illegible] grouping of the *ions* to form the elementary [illegible], has been *illustrated* by a multitude of [illegible] slightly dissimilar, to represent *ions* of [illegible] electrical charge. These magnets were [illegible] corks so as to float in water: when three [illegible] indifferently in the water, with a controlling [illegible] took up position at the angles of a tri- [illegible] in the water, rested at the corners of a [illegible] the angles of a pentagon. When six [illegible] in the water, and the controlling pole [illegible] the center, and the five others grouped into [illegible] a pentagon about this; with eight, two took [illegible] the encircling group, and this arrangement [illegible] inner and outer—continued up to eigh- [illegible] this, there were three systems—an inner, [illegible] for a still larger number of magnets, four

systems, and so on. For example, several combinations are shown in (*A*), (*B*), (*C*), (*D*), and (*E*), Fig. 209, and one of

(*A*)	(*B*)	(*C*)
1; 5 = 6	2; 6 = 8	3; 8 = 11
1; 5; 9 = 15	2; 8; 10 = 20	3; 7; 10 = 20
1; 6; 11 = 18	2; 7; 12; 14 = 35	3; 8; 13 = 24
1; 6; 10; 12 = 29		3; 7; 12; 14 = 36
1; 7; 12; 14 = 34		

(*D*)	(*E*)
4; 9 = 13	5; 9 = 14
4; 8; 13 = 25	5; 9; 12 = 26
4; 9; 14; 15 = 42	

FIG. 209.

these—(*B*)—is illustrated by Fig. 210: the number following the sign of equality (=) denotes the total number of

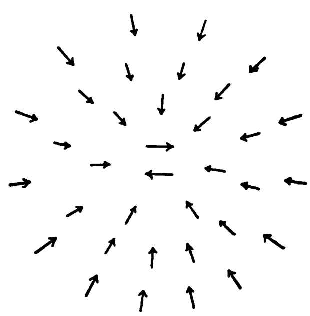


FIG. 210.

magnets in the combination, and those preceding the sign, the number of systems and the number of magnets in each system; thus, in (*B*), 2; 7; 12; 14 = 35, means that there were 35 magnets in all in the water, two in the inside group, seven in the next, twelve in the third, and fourteen in the outside configuration.

Section Four: Coincidence of Sun-spots, Auroras, Magnetic Storms, Telluric Currents, and Telegraphic Interruption.

161. Whether the phenomena described in this Chapter have such mutual connection and dependence that one gives rise to another, or whether all are due to some primary physical cause, are questions that are yet debatable; and many plausible arguments are advanced by those entertaining differing views on the subject: but the fact is beyond dispute, that however many instances may be cited of one of them having occurred independently of the others, still there are numerous striking *coincidences* of two or more, and this removes the matter beyond the accusation of mere chance. It is evidence of a positive nature extending over many years and throughout the globe, and is worthy of more consideration than the mere negative kind that the phenomena have been observed separately.

Some of the most notable coincidences will now be cited, after a few words on the nature of telluric currents.

162. Telluric currents.—That our atmosphere has periodic convulsions with blinding electrical displays, is a matter of common knowledge: they upset telegraphic operations; the heavily charged masses of air induce currents in the wires as they sweep over them, just as any other changing electrical field would. They are either counter-currents to the regular battery supply, or more current than is manageable, and in either case create disorder.

This disorder also comes from another source, and thus we have to distinguish between two kinds of earth-currents—those that arise with the passing storm and have only its evanescent existence; and those that are due to a difference of potential at two points of the Earth—that vary in direction and strength, but are ever present in some degree—that

have no kinship with meteorological disturbances, but are most powerful and erratic even *during the appearance of an aurora.*

It is of these latter currents we shall treat. They belong to the crust of the Earth, and were first noticed *during the aurora* of Oct. 28, 1848, *by their interruption of telegraphic communication.* They have since been the subject of enquiry by numerous observers in divers countries, who have conducted experiments on telegraphic lines leading to every point of the compass. The results are too various to classify in a few categories *as to direction*, but their characteristics in widely separated localities are so accordant that they are at once seen to be general phenomena. They can set a telegraph call-bell ringing, throw the mechanism out of gear, and even be a source of personal danger.

The essential mode of observing them is to insert the ends of a very long insulated wire in the ground (as is practically the case with telegraph lines) and place a galvanometer in circuit: when the two points of contact with the Earth are at different potentials, a current will pass, whose strength and direction will be indicated by a deflection of the needle. If one end of the wire be taken out of the ground, of course no *terrestrial* current can enter it; whereas, if the current be due to influence—as of a passing electrified cloud,—the current becomes stronger at the other end, having only that to discharge from.

True telluric currents may be due to the changing field of terrestrial magnetism; they may be the flow through Earth of the auroral flush in air, or the latter may be the reflex of the former: all these explanations are made. If they are considered composed of two general streams—one with the parallels and the other with the meridians—the resultant, that is, the actual system experienced, would suffice to explain the directive force of the Earth on the magnetic needle—that is, terrestrial magnetism; and the unequal fluc-

tuations of both systems of currents would then account for the periodic changes in the magnetic elements.

163. The currents and magnetism of the Earth connected. —The classification of various natural phenomena and placing them side by side to note their coincidence—their rhythmic occurrence, and thus infer their connection and cause—has been a favorite practice of inquiring minds for ages.

A recent writer has said: "There is one potent cause which for a large part rules all meteorological and magnetical phenomena and influences them in a similar way nearly simultaneously." To substantiate this statement, he traces side by side for the same general locality—Holland—the curves of Temperature for fifty years, of Horizontal Magnetic Intensity for thirty-three years, of Vertical Intensity for thirty years, of Variation, Rainfall, and Barometric Pressure, each for a certain number of years, and all covering more or less the same period of time.

A succession of maxima and minima characterize all these curves, which occur with much simultaneity of time, especially in the cases of Temperature, Horizontal and Vertical Intensity: for the whole period, there is a steady creeping up in these three quantities from January to the middle of July, when a level occurs until the middle of August, and then a rapid descent takes place until January.

Whatever the "one potent cause" of all, it does not affect them equally—some are more sensitive than others, so that their fluctuations are more extreme and also more quick to occur than others, which seem sluggish and lag behind; but, as a general rule, a maximum or a minimum in one has a corresponding feature in each of the others at the same time and place, even over the extent of a continent.

It is the purpose in this Section to adduce coincidences of only such phenomena as bear directly upon disturbances of magnetic needles—the Compass, in particular.

From the Magnetic Observatory near Paris three special lines of telegraph have been laid for observation of the currents jointly with magnetic changes: one runs north and south, one east and west (both ten miles long), and the third a closed circuit of two and one-half miles diameter; on each line a galvanometer is placed in circuit, and its indications are recorded by photography like that of the magnetographs.

Comparison of both phenomena shows complete identity of the curve of Horizontal Intensity with that of a current from east to west; the Dip and a north and south current are less accordant, sometimes agreeing and again conflicting, while the perturbations are of the same extent; though in general a current from north to south corresponds with an increase of Dip, and conversely. The currents often precede the magnetic changes by two or three minutes (which fact was also found to be the case in England and Russia), and again their simultaneity is often perfect. Thus the direct connection of telluric currents and terrestrial magnetism is established; incidentally, it will receive further confirmation as we proceed to extend the kinship of both to auroras.

164. Connection of auroras, earth-currents, magnetic disturbances, and telegraphic disorder.—The Earth and its atmosphere have been compared to an induction-coil—telluric currents being the primary cause of which the auroras are the secondary effects; for electrical movements occur in the upper strata of air when these currents undergo rapid variation.

This was illustrated by the great aurora of September 1st and 2d, 1859, visible all over the American Continent, and which daylight alone, no doubt, prevented being seen in Europe, where the following remarkable disorder in telegraphy was caused by earth-currents *coincidently* with the auroral display elsewhere: "At all the telegraphic stations in France the service was impeded during the whole of September 2d, but especially at two periods of the day, from 4.30 a.m. to 9 a.m. and from noon to 3 p.m. These two periods were the

same at all stations, and the greatest disturbances took place exactly at the same hours, at 7 a.m. and 2 p.m. The phenomenon consisted in a current producing continuous attraction of the armatures of the electromagnets; a galvanometer introduced into the circuit showed that the current changed its direction at varying intervals of time, of at least two minutes' duration. Towards 7 a.m. and 2 p.m. these currents were so strong that when the wire was isolated, and a conducting substance presented to it, it gave off vivid sparks. The currents manifested themselves in all directions; they seem, however, to have been more marked on the lines which went from north to south. The longest wires always showed the greatest disturbances." (Blavier.) "The same day telluric currents were also observed in the greater part of the two hemispheres, in Switzerland, in Germany, in the British Isles, in North America, and throughout Australia. In the United States, in particular, they were so strong that for about two hours it was possible to send messages from Boston to Portland, and *vice versa*, without any battery, using only the telluric current." (Angot.) And again: "On May 30, 1869, *during the aurora borealis*, which was visible from 7 to 9 p.m., it was observed that out of the sixteen lines which terminated in the telegraph office at Basle, six were almost useless during the two hours that the phenomenon lasted; on the others the telluric currents were not strong enough absolutely to interrupt communication.

"Similar coincidences were also observed during the auroras of April 5, and October 24, 1870; and the telluric currents attained an extraordinary development during the aurora of February 4, 1872, which was one of the most extensive known: it was seen in the whole of the west of Asia, in the north of Africa, throughout Europe, and on the Atlantic as far as Florida and Greenland; at the same time an aurora was observed in part of the southern hemisphere. The disturbances in telegraphic communication were not less ex-

tensive, and were observed with great care in great part of Europe. In Paris they began on the lines directed eastward, those to Germany and Austria, then on that to Switzerland. In Germany all the lines were affected, and communication was for a long time impossible between Cologne and London; in that country the most marked perturbations were observed on the lines directed east and southeast. These currents were also observed in Italy and in Turkey. At the same time many of the submarine cables were so affected as to prevent the transmission of any messages; the disturbance was especially marked on the line from Lisbon to Gibraltar, on the Mediterranean cable, on the line from Suez to Aden, and from Aden to Bombay, and finally along the transatlantic cable from Brest to Duxbury.

"Lastly, during the great aurora of November 17, 1882, the telluric currents observed in England were, according to Preece, five times as strong as the current usually employed in telegraphy. Communication was interrupted as long as the disturbance lasted." (Angot.)

This testimony of observers of the phenomena is explicit as to the intimate connection of auroras, earth-currents, and telegraphic circuits.

To extend the relationship to the magnetic elements is but a step—merely to recall their joint variation with telluric currents; or, to state the matter as it probably exists, the phenomenon we call terrestrial magnetism is due to currents in the Earth, and the *fluctuation* of these gives rise to two separate phenomena; first, differences of potential which become manifest in wires as electrical currents, and, secondly, changes in the magnetic elements, as indicated by the movement of needles arranged to show Variation, Dip, and Intensity.

Then while the primary currents flow gently on, like the smooth river following only the natural depths and shallows of its bed or the sinuosities of the banks, there will be but the

normal variability of currents in the wire and small movement of the magnetic needles; but, as when the river tumbles over rocks and boulders its water is broken into foaming spray and swirling eddies, so the wire currents and magnetic elements show erratic and wild movement when their source is greatly disturbed.

Such a period covered the last days of August and the first days of September of the year 1859, celebrated not only for a great aurora, widespread telegraphic interruption, and strong earth-currents, but also for the most violent magnetic storm ever known and which was experienced all over the world. "At Melbourne, Australia, the great aurora of August 29, 1859, was accompanied by violent magnetic perturbations, 1° 9′ in the Variation, and by interrupted telegraphic communication; now *these disturbances preceded the aurora*, which only appeared at the moment when the telegraphic communication began to improve." (Angot.) And all this without any very unusual atmospheric disturbance in the localities magnetically affected.

It was at Upsala in 1741 that irregularity of the Variation was first observed during an aurora; and in the following six years, forty-six examples of such coincident disturbances were noted. It was subsequently observed that the Dip, and finally the Intensity, shared the disturbance during auroral displays. And these facts have since been abundantly verified by a host of observers throughout the globe.

Observation has brought out other facts: that, with very few exceptions, the center of the auroral crown coincides with the magnetic zenith; and that the magnetic disturbance almost invariably *precedes* the aurora when not simultaneous with it. This would lend support to the theory that violent changes in terrestrial magnetism is one cause of the aurora. "The magnetic association founded by Gauss and Weber in 1834, and the stations organized by Sabine in a certain number of English colonies, greatly increased the number of ex-

amples of coincidence between the polar auroras and perturbations in the three elements of terrestrial magnetism. "But they also testify to the complexity of the question. For though the great magnetic perturbations, which occur simultaneously in the two hemispheres, seem to be always accompanied by very extensive auroras, this is not the case with more ordinary disturbances. These often appear to be due to local causes; they are not noticed at the same time in the two hemispheres, or, in the same hemisphere, are not manifested at the same time in Europe and America. . . . The motionless arcs and faint auroras, or those with slow movements, are generally unaccompanied by the slightest agitation of the magnetic needle; magnetic perturbation is, on the contrary, very marked during auroras with distinct outlines, and those which present luminous rays of a defined character and rapid movements; the greatest deviations of the Compass correspond to the appearance of great rays, colored red and green, which flash suddenly, like lightning. . . . During the expedition of the *Polaris*, Bessels noted a change in the Variation of 12° on February 4, 1872, a little before the appearance of the great aurora of that day; he remarked, moreover, that on that occasion the magnetic disturbance preceded the aurora by about six hours." (Angot.)

165. Connection of sun-spots, solar outbursts, magnetic disturbances, and auroras.—A distinction must be made between quiet sun-spots and those accompanied by violent eruptions; the latter are easily recognized by the spectroscope, and are alone related to the aurora. The following is an instance of all three—sun-spots, eruption, and aurora, occurring together; the writer is treating of *sun-spots* alone, and then goes on:

"At times, though very rarely, a different phenomenon of the most surprising and startling character appears in connection with these objects; patches of intense brightness suddenly break out, remaining visible for a few minutes, moving

while they last with velocities as great as one hundred miles *a second.*

"One of these events occurred on the forenoon (Greenwich time) of September 1, 1859, and was independently witnessed by two well-known and reliable observers, Mr. Carrington and Mr. Hodgson. Mr. Carrington at the time was making his usual daily observation upon the position, configuration, and size of the spots by means of an image of the solar disk upon a screen, being then engaged upon that eight years' series of observations which lies at the foundation of so much of our present solar science. Mr. Hodgson, at the distance of many miles, was at the same time sketching details of sun-spot structure by means of a solar eye-piece and shade-glass. They simultaneously saw two luminous objects, shaped something like two new moons, each about eight thousand miles in length and two thousand wide, at a distance of some twelve thousand miles from each other.

"These burst suddenly into sight at the edge of a great sun-spot, with a dazzling brightness at least five or six times that of the neighboring portions of the photosphere and moved eastward over the spot in parallel lines, growing smaller and fainter, until in about five minutes they disappeared, after traversing a course of nearly thirty-six thousand miles. Their passage did not seem in any way to change the configuration of the spot over which they passed. Mr. Carrington found his drawing, which was completed just before they appeared, still quite correct after they had vanished. Of course it is possible to question the connection between this phenomenon and the spot near which it appeared; but as somewhat similar appearances have been seen by other observers since then, and always in the neighborhood of spots, it is probable that there is some relation in the case. . . .

"Some express the opinion that it was caused by some sudden and *powerful eruption from beneath, such as the spectroscope often reveals* to us nowadays; an eruption, however, of most

unusual brilliance and violence, for not one of the outbursts since then observed by the spectroscope has ever been visible without its aid.

"The event occurred in the midst of a remarkable magnetic storm: from August 28th to September 4th, there were auroras every night all over the world, and the earth-currents were often so strong as greatly to interfere with telegraphic communication." (Prof. Young.) "There are a number of observed instances, which, though not sufficient to demonstrate the fact, still render it very probable that every intense disturbance of the solar surface is propagated to our terrestrial magnetism with the speed of light. An instance fell under the writer's [Prof. C. A. Young] notice in the course of a series of spectroscopic observations at Sherman. On August 3, 1872, the chromosphere in the neighborhood of a sun-spot which was just coming into view around the edge of the sun, was greatly disturbed on several occasions during the forenoon. Jets of luminous matter of intense brilliance were projected, and the dark lines of the spectrum were reversed by hundreds for a few minutes at a time. There were three especially notable paroxysms—at 8.45, 10.30, and 11.50 a.m., local time. At dinner the photographer of the party, who was determining the magnetic constants of the station, told me, without knowing anything about my observations, that he had been obliged to give up work, his magnet having swung clear off the scale. Two days later the spot came around the edge of the limb. On the morning of August 5th I began observations at 6.40, and for about an hour witnessed some of the most remarkable phenomena I have ever seen. The hydrogen lines, with many others, were brilliantly reversed in the spectrum of the nucleus, and at one point in the penumbra the *C* line sent out what looked like a blow-pipe jet projecting toward the upper end of the spectrum and indicating a motion along the line of sight of about one hundred and twenty miles a second.

This motion would die out and be renewed again at intervals of a minute or two. The disturbance ceased before eight o'clock and was not renewed that forenoon. On writing to England, I received copies of the photographic magnetic records for those two days, which show that on August 3d, which was a day of general magnetic disturbance, the three paroxysms I noticed at Sherman were accompanied by peculiar twitches of the magnets in England. Again, August 5th was a quiet day, magnetically speaking, but just during that hour, when the sun-spot was active, the magnet shivered and trembled. So far as appears, too, the magnetic action of the Sun was instantaneous. After making allowance for longitude, the magnetic disturbance in England appears strictly simultaneous with the spectroscopic disturbance seen on the Rocky Mountains. . . . Solar disturbances are not *the* cause of our magnetic storms, but one cause of some of them; and very likely a cause only in the sense that the pulling of a trigger 'causes' the flight of a rifle-ball: there need be no *proportionality* between such a cause and its effect." (Prof. Young.)

As often remarked, it took years to bore and tunnel and mine the Hell Gate obstruction in the East River, New York, but the pressure of a child's finger on an electric button for a fraction of a second sent the huge mass of rock flying into the air.

The periodic fluctuation of the Variation—daily, yearly, and secular—has already been explained: there are other regularly recurrent maxima and minima superposed upon these, like the harmonics upon a fundamental note; and the most important one of them will now be mentioned on account of its direct connection with the subject-matter of this Chapter.

The regular daily fluctuation of the Magnetic Variation differs in amount according to locality; but an examination of the records of any one Observatory for a very long time, discloses the fact *that this amount itself undergoes a steady in-*

crease and decrease during a period of about eleven years; that is, there is a regular ebb and flow of the great magnetic tides of the globe whose period follows most closely the period of maximum and minimum number of sun-spots. This becomes more striking by tracing, as is done in Plate K, the curves of both phenomena: "From 1820 to 1895 the record is almost continuous, and the coincidence of the curves is such as to make it impossible to doubt the connection."

But both these phenomena are also closely allied to auroras, as may be seen from data carefully and thoroughly collated by Prof. Loomis: "We find an almost perfect parallelism between the curves of auroral and sun-spot frequency. . . . Occasionally, magnetic storms occur during which the compass-needle is sometimes almost wild with excitement, oscillating 5° or even 10° within an hour or two. These storms are generally accompanied by an aurora, or an aurora is *always* accompanied by magnetic disturbances." (Prof. Young.)

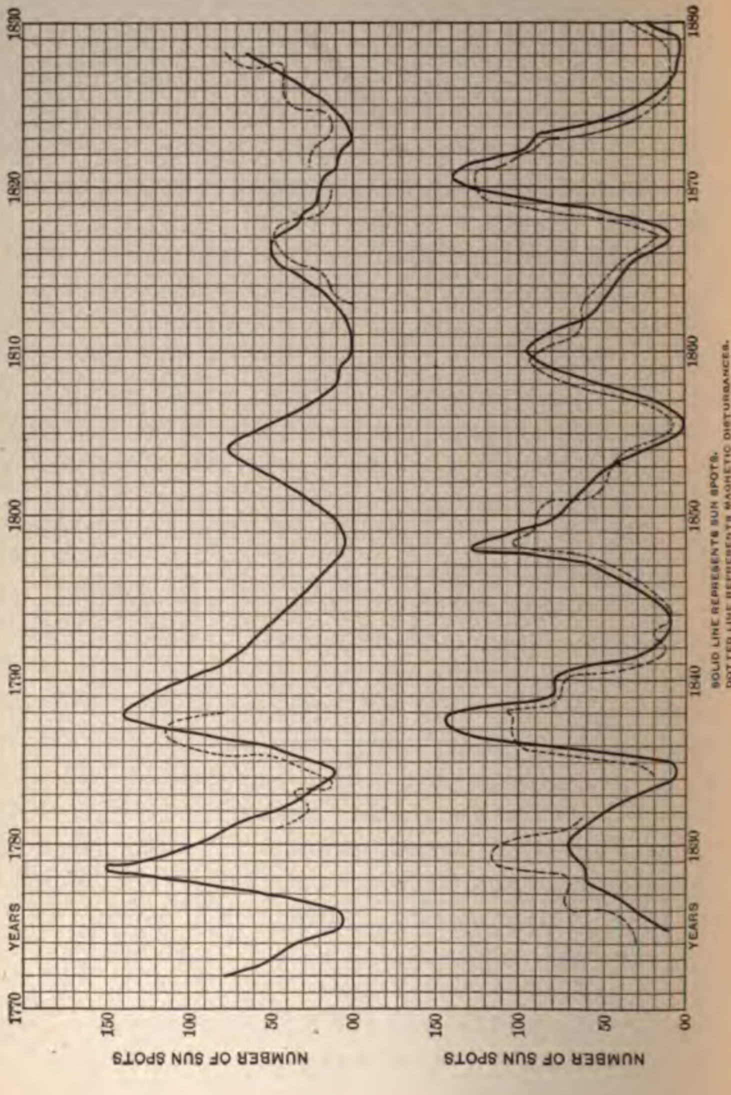
Between 1873 and 1892, "we have three magnetic storms which stand out pre-eminently above all others during that interval. In that same period we have three great sun-spot displays which stand out with equal distinctness far above all other similar displays. And we find that the three magnetic storms were simultaneous with the greatest development of the spots. Is there any escape from the conclusion that the two have a real and binding connection? It may be direct; it may be indirect and secondary only; but it must be real and effective." (Mr. Maunder of Greenwich Observatory.)

From observations at Turin, Italy, extending over a period of 148 years, that is, since 1752, Prof. Somis, of the Royal Academy of Science, has made comparison of sun-spot frequency with the Temperature of the Air; and he finds that the eleven-yearly recurrence of the former is also well marked in the latter.

As a result of his investigation, he states that the eleven-

Plate K.

MAXIMA AND MINIMA OF SUN SPOTS AND MAGNETIC DISTURBANCES.



SOLID LINE REPRESENTS SUN SPOTS.
DOTTED LINE REPRESENTS MAGNETIC DISTURBANCES.

yearly fluctuation of the sun-spots and the mean temperature at the Earth's surface are due to some periodic cause, which —acting at the Sun, increases the Spots; and, acting at the Earth, increases the Temperature, with a retardation in time of a quarter of this period: on the other hand, a similar cause acts on the Earth, diminishing the Temperature; and on the Sun, increasing the Spots, with a like retardation.

At Toronto (Canada) and Hobartown (Tasmania) a simultaneous progressive increase in Magnetic Disturbances and Variation was observed between 1843 and '48, amounting to forty per cent of the whole: now in the former year there was a minimum of sun-spots and in the latter a maximum; and this coincidence of phenomena on Sun and Earth, as well as at the utmost extremes of the latter, clearly pointed to the cause being cosmical.

Ever since that time the matter has been diligently investigated by many inquirers; but, for the purpose of this Treatise, it will suffice to present the results obtained by Mr. William Ellis of the Royal Observatory, Greenwich, in the form of curves denoting the course of each phenomenon, Plate L. The upper curve represents sun-spot frequency during the years from 1841 to 1896; the middle curve, the range of the Variation Magnet; and the lower curve, the fluctuation of the Horizontal Intensity: it is needless to comment upon the coincidence of all three—even in every twist and turn, however small, their sinuosities correspond.

Thus, of the phenomena treated in this Chapter, some—earth-currents, magnetic disturbances, and telegraphic disorder—are of unquestioned electromagnetic origin; others—auroras and sun-spots—have been shown to possess close intimacy with a periodic fluctuation of the magnetic elements, following almost exactly in their steps; and electrical discharges in high vacua have been proven like unto auroral streamers and colors: therefore, as a consequence of all this varied relationship, it is fair to infer that auroras also have an

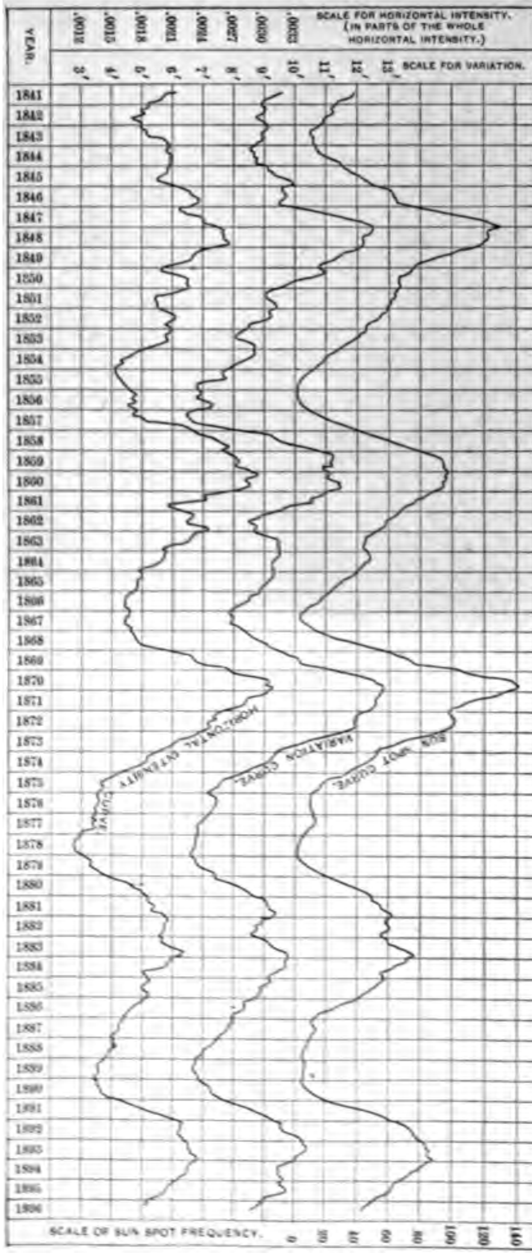


PLATE L.—COINCIDENCE OF SUN-SPOTS AND MAGNETIC PHENOMENA.

electromagnetic origin, and that eruptive sun-spots are, at least at times, their genesis.

Of course auroras may have other sources: electromagnetic waves from the Sun; commotions in the electricity of our atmosphere; a violent wrench to the normal condition of terrestrial magnetism—in fact, any extensive disturbance of the ether, electromagnetically, that will send out huge waves and suffuse the rarer aerial regions with color.

CHAPTER X.

THE MAGNETIC CONDITION IN BODIES OF RESTRICTED SIZE; FIELD AROUND THEM; LAWS OF ACTION; EFFECT OF HEAT ON MAGNETISM.

Section One: Magnets, Natural and Artificial.

166. Up to the present point, electromagnetic phenomena have been viewed in their widest range—in Earth and Air and throughout Space even to the Sun; but now the electromagnetic condition must be considered in bodies of definite size; later on, the view will be narrowed to the limits of the atom, and then the most rational theory yet advanced regarding the exact nature of electricity and magnetism will be stated.

167. The lodestone.—Throughout Nature is found more or less abundantly a reddish-black ore, both in lumps and in the crystalline form, which has the property of attracting to itself bits of iron: they adhere in greatest quantity about two points or poles, however irregular the lump may be.

The ore is an oxide of iron—a union of 73 parts of iron and 27 of oxygen in 100 of both, or, in chemical formula, Fe_3O_4, and is mixed with some earthy matter; it is called magnetite by the mineralogist. It was widely known in remote antiquity, and the property of attracting iron served to give it in each country a name descriptive of this peculiarity. That of "magnet," however—derived from the province of Magnesia in Asia Minor, where it was found in great quantity—has survived, to become its distinctive appellation.

It was known to the ancients that it would impart its virtue to iron by rubbing, so that this would in turn act as a magnet: this is proven by the following extract from the poem *De Rerum Natura* by Lucretius, who flourished about sixty years before the Christian era. Translation by Dr. Busby.

> Now, chief of all, the magnet's power I sing,
> And from what laws the attractive functions spring;
> The magnet's name the observing Grecians drew
> From the magnetic region where it grew;
> Its viewless potent virtues, men surprise,
> Its strange effects they view with wondering eyes,
> When, without aid of hinges, links, or springs,
> A pendent chain we hold of steely rings
> Dropt from the stone—the stone the binding source—
> Ring cleaves to ring, and own magnetic force:
> Those held superior, those below maintain,
> Circle 'neath circle downward draws in vain,
> Whilst free in air disports the oscillating chain.

About the tenth century it was discovered that if a piece of this ore were suspended by a thread so as to hang horizontally, it would settle into a definite direction—the magnetic meridian: this made it at once a most valuable guide or leader both afloat and ashore, and accordingly it received the name of Lodestone, or leading stone, from the Saxon word *Laedan*, to lead.

168. The steel magnet.—According to its temper and quality, a mass of iron or steel of any form—wire, rod, or bar—may be converted into a magnet of more or less power. The means to this end are various, with corresponding differences of effect. The magnetic condition can be produced by holding a bar in the line of Dip and striking it on end with a mallet; but the mild influence of terrestrial magnetism will thereby yield only a feeble magnet: powerful steel magnets drawn over the bar will impart a proportionate measure of their own strength: while the field of an electric

current traversing a spiral coil of wire in whose axis a bar is placed, will make of this the strongest magnet possible.

There is a limit, however, beyond which no method will increase the power of a magnet. To understand this, as well as to afford a mental image of a magnet, various conceptions of its interior structure have been formed: the two principal are, 1st, that each molecule of the iron is itself a magnet, and 2d, that a closed current of electricity is forever circulating round the limiting surface of each molecule. In the neutral state, or when the bar exhibits no magnetism, these atomic magnets, or molecular currents, are heterogeneously mingled—their axes point in all possible directions; while the process of magnetization is only the tendency of a magnetic flow to turn their axes all one way: a slight ripple through their midst will turn but a few; a strong wave will wheel about many; and a powerful flood will swing all into line, and then the process can do no more—the magnetic condition is complete. But it will not remain so: the natural tendency of the little magnets or currents is to return to their helter-skelter condition—some will do so, even in the most highly tempered steel, and the magnet thus loses strength, according to universal experience.

Twisting a wire is essentially a derangement of its molecules—the act excites magnetism in the wire—and this shows that the magnetic condition is molecular.

The use of the electric current to induce the magnetic condition will be treated in the chapter on making compass-needles, and the means are so effective and so generally available, that it is almost needless to describe the process by bar-magnets; but the emergency may arise when this is the only means at hand.

If only one magnet is available, it is to be held vertically and passed from left to right over the bar to be magnetized (laid flat on the table) so as to touch every part of its surface: begin at (1) Fig. 211, a little distance from the bar, and end

at (3) a little beyond it; at the latter point, raise the magnet vertically a foot above the bar, carry it at this height and in this way to the left, bring it down to touch the bar again at (1), and make the pass to the right as before; do this several

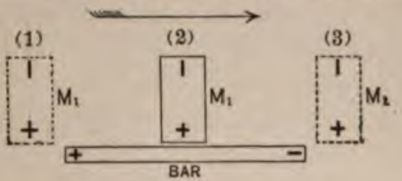


FIG. 211.

times; then turn the bar over and repeat the same number of passes on the other side.

When two magnets can be had, they are to be held one in each hand, slightly inclined to the horizon, lower poles of opposite name, and joined as in Fig. 212: then draw them

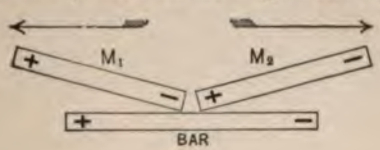


FIG. 212.

apart and beyond the ends of the bar, raise them well above the latter, bring them back to its center, and make another

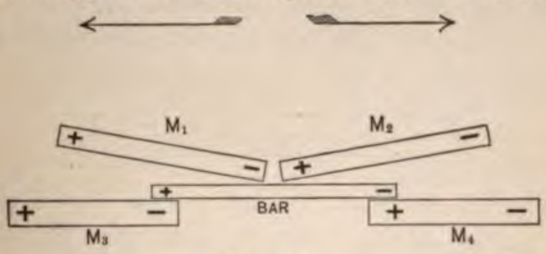


FIG. 213.

pass, and several more as at first; the same number, made in the same way, to be repeated on the other side of the bar.

With four magnets, the procedure is identically that with

current traversing a
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are, 1st, that each … at different points
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169. **The electromagnet.**—Usually, an electromagnet is thought of as a kind of spool wound with insulated copper wire in overlying layers, through which an electric current may be sent; but in reality, the shape that bears the circuit may be most varied—round, square or horseshoe, flat or elongated, solid or tubular, regular or irregular; and each will have the same characteristics—behave like a steel magnet in every particular when alive with current. But it is active *only* when its life-blood circulates—inert, when this ceases to flow; and either condition may be imparted to it by the pressure of a button.

The power of an electromagnet increases with the strength of the current, or, this remaining constant, with the number of turns of the wire; therefore with both: if the form be tubular, to fill the core with soft iron—the purest wrought iron, for instance—will further add to the strength: if the form be cylindrical, and we could see the current circulating through the wire as a material fluid, it would seem to flow *contrary* to the hands of a watch, looking at one end full in the face, and this is the north pole; while it would be *with* the hands of the watch if we view the other end, and this is the south pole. The rule is universal, whatever the form of the magnet.

170. **The electro-static magnet.**—When two insulated metal spheres of same size are charged with equal quantities of like or unlike electricity by a Wimshurst machine, and are separated by the distance of a few diameters, the ether around them is in a state of strain exactly like that surrounding the like or unlike poles of a steel magnet or an electromagnet, and may be rendered apparent to the eye by the same means, viz., strewing fine iron dust on a sheet of paper above them. The lines of force thus made visible are, as it were, threads of the highly elastic ether which may be stretched indefinitely without snapping—so great is the elasticity of the ether; so that, removing one of the spheres to

two, only that t… …to finest tenuity
213, to lap the… …a charge of elec-
If a sheet of… …there is an equal
non-magnetic… …nother body. In-
the bar, these… …stress in the sur-
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If the bar… …may be called the
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the steel, the…
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By mean… …by its effects.
the strength… …ass-needle; but
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The magnet M is then put in place—vertically in a groove of a board B so that it may be moved up, with means to clamp it: a scale at the side indicates the distance moved through,

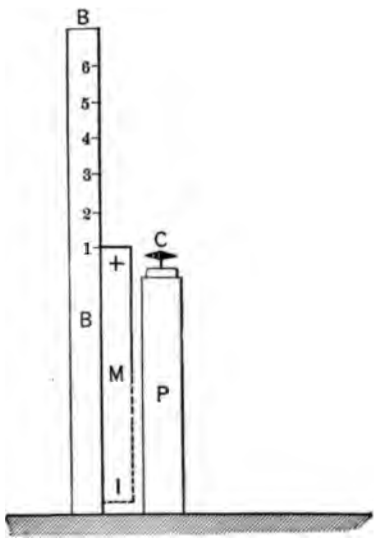


FIG. 216.

and as the end of the magnet reaches each mark, the needle is oscillated for the same time as at first—one minute.

By Terrestrial Induction, the magnet is temporarily strengthened when one pole is uppermost, and weakened when the other is: to get at the magnetism proper of the bar, therefore, oscillations must be made with it in both positions, and the mean taken. Suppose these *means* to be 34, 30, 26 . . . respectively, with the magnet-end at the points 1, 2, 3 . . . of the scale, and that the number due to the Earth alone is 10; then the values of the force at the corresponding distances from the end of the magnet are $34^2 - 10^2 = 1056$; $30^2 - 10^2 = 800$; and $26^2 - 10^2 = 576$.

Continuing the oscillations, it would be found that they steadily decrease until the magnet has risen about half its length, where they are practically the same as under the in-

any distance, will only draw out the thread to finest tenuity —not break it: therefore, wherever we find a charge of electricity on a body, we must consider that there is an equal charge of opposite kind, somewhere, on another body. Indeed a charge necessarily carries with it a stress in the surrounding medium, and this stress implies a pull somewhere; for it is inconceivable that a burden should experience the tug of a rope attached to it without some power holding at the other end.

There is, then, no such anomaly as an isolated charge—the positive needs the negative for its existence, though we may see but one—and thus we have what may be called the electro-*static* magnet, in complete analogy to the electromagnet and the steel magnet.

171. **Distribution of magnetism in a bar.**—The distinctive virtue of a magnet becomes apparent only by its effects, as for instance, its power to deflect a compass-needle; but this power is not the same at all points of the magnet's surface, and to determine its varying value, is to ascertain the distribution of magnetism in the bar. Roughly, it may be done by rolling the magnet in a heap of iron filings: it will come out thickly coated with them in some parts and almost nude in others—the former indicate magnetic strength, the latter its weakness.

For accuracy, however, recourse must be had to method of oscillation or induction, the latter being the most accurat *By Oscillation.* In another part of this Treatise, it is prov that a body swinging under the influence of a central forc as a pendulum by gravity or a compass-needle by magnetis will make a certain number of oscillations in a given time, pendent on the intensity of the force; and that the sq the number of oscillations becomes an index of t Using this principle, a small needle, delicately n to move in a horizontal plane, is set upor 216, and oscillated for, say one mini of the Earth's magnetism alone.

If, now, the magnet be laid across the meridian, as in Fig. 217, and the values 1056, 800, 576, . . . be laid off according to any scale of equal parts as ordinates Ax', Bx'', Cx''', etc., to the successive distances 1, 2, 3 . . . of Fig. 216, used as abscissas Nx', Nx'', Nx''', etc.,—to the northward for one-half the magnet and to the southward for the other half—and the ends of the ordinates be joined, a curve will be traced ABC . . . M . . . $C'B'A'$, which is characteristic of the magnetic intensity of the bar; and however varied in size and strength the magnet may be, this curve—typical of its magnetic distribution—will be substantially the same.

If the normal components are determined at sufficiently close intervals, the ordinates that represent them will form the area bounded by a branch of the curve, by the end-ordinate, and by half the length of the magnet: the center of gravity g of this area is the point of application of the *resultant* R of these ordinates or parallel forces: prolonging the resultant of each group to the axis of the magnet, $\widehat{ll'}$, we have the magnetic couple $R - \widehat{ll'} - R'$ acting on the bar, or the *magnetic moment* $R \,.\, \widehat{ll'}$, which, jointly with the Earth's couple, turns it into the meridian when free to move.

The effort to turn is the greatest in the position shown, for the *perpendicular* distance between the forces R and R'—one factor of the Earth's couple—will decrease with the angle the bar makes with the magnetic meridian.

While the magnetic moment *may* be found graphically in this way, the method is not given as a means of doing it, but to show clearly what the quantity is.

By Induction. Whenever a loop or coil of wire is moved in the vicinity of a magnet, or the latter near the former, a current of electricity is temporarily induced in the wire; it is the variable magnetic field encountered in either movement that excites the current: this is the principle of the *Induction* method.

A ballistic galvanometer is used to indicate the current,

and it may be said that its distinctive feature is a heavy needle whose slow movement is a kind of summation—an integration, as it were, of the several impulses of the transient current: the *sine* of half the angle of the first swing is proportional to this current, and as the latter is much or little according to the field traversed by the wire, the angle of swing therefore becomes an index of the field.

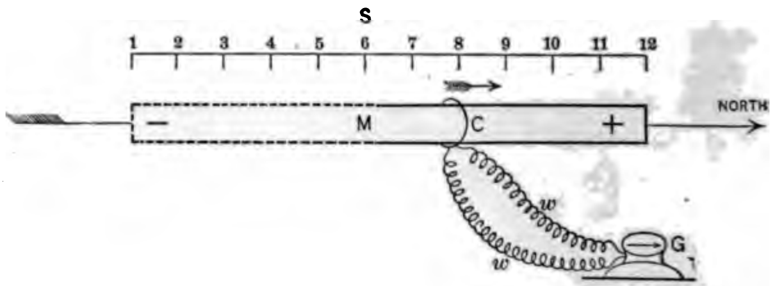


FIG. 218.

The magnet M is placed as in Fig. 218, horizontally in the magnetic meridian, and two sets of observations made with each pole successively toward the north. A single loop of small wire, C, close fitting, and connected to the galvanometer, is placed on the magnet, and slipped quickly from one

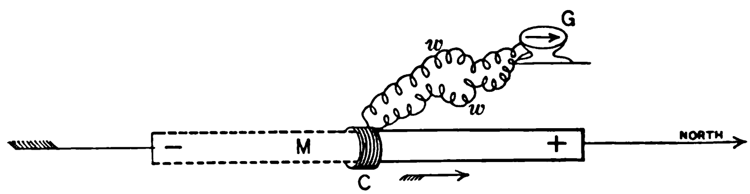


FIG. 219.

division to another of the scale, S, resting at each long enough to note the swing of the needle and allow it return to zero. The plane of the loop is at right angles to the length of the magnet, so that the several deflections indicate only values of the normal component of the magnet's total inten-

sity—the same as in the oscillation method. To obtain their resultant, a coil of insulated wire is placed as in Fig. 219, at the middle of the bar, and drawn quickly toward the north—off the magnet, and beyond it a few inches, noting instantly the throw of the needle; this is done with the other pole toward the north: and both movements of the coil are repeated toward the south with each pole alternately in that direction.

The mean deflection for each half of the bar is an index of the resultant of the group of parallel forces acting on it.

To convert the angular indices of the individual forces, as well as the index of their resultant, into absolute measure, both loop and coil are taken off the magnet and away from its influence, and connected with some source of electricity: a sudden current—either " make " or " break," is then sent through coil and loop, and the deflection of the needle noted in each case.

The field of this current can be measured in dynes, and comparison of the deflection it causes, with those observed when the loop and coil were on the magnet, afford the means of determining the normal components and their resultant in absolute measure—dynes.

172. Characteristics of a magnet.—From the preceding, it is evident that the distinctive features of a magnet are two foci of strength—one near each end—shading off in intensity toward a neutral ground in the middle. These foci are called poles, and have opposite qualities, since they produce dissimilar effects—one attracting one end of a suspended needle, while the other repels the same end. If a bar-magnet be placed on a slab of cork and floated in water, it will turn until its axis is in the magnetic meridian; but it will not then move either north or south: this proves that the poles are of equal strength—that it is truly a magnetic couple that acts on the bar; and yet, if the bar be placed with its axis at right angles to the meridian on a table, and a small needle, free to oscillate in a horizontal plane, be set at some distance, one pole

of the magnet may produce a different deflection from the other pole, indicating an apparent inequality of power. The real explanation of this is, that the strength is concentrated in one-half the magnet and diffused in the other half, and the difference in distance of the resultant of each from the end of the bar produces the difference in deflection: this resultant is the same, however, as if the individual forces had been symmetrically spread over each half of the bar; and the pole must therefore be thought of as the point of application of the resultant of the parallel forces acting on each half of the magnet.

Irregular distribution may be due to some *peculiarity* of the steel, or of tempering, or of magnetizing, or of all combined; but either pole cannot be called into existence in greater or less degree than its congener, *and there is no such thing as a magnet with one pole.*

Since attraction occurs only between poles of opposite

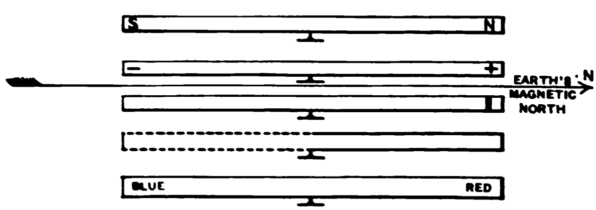


FIG. 220.

name, the end of the magnet that points to the terrestrial north should in strictness be called a south pole; but custom has decreed otherwise, and better than run counter to this, would be the tacit understanding that the polarities differ, and continue to call both the magnetic pole of the Earth and the pole of the magnet that points to it, by the same name, and this is done throughout this book.

Fig. 220 represents the various means—letters, colors, and marks—that are used to distinguish the poles.

By extensive experiments, it has been found that in magnets of seven inches and upward, the poles are 1.6 inch from the ends; and in magnets of less length, they are located at one-sixth the length from the ends.

Section Two: The Magnetic Field.

173. Magnetic bodies are surrounded by a field of influence.—In 1576, Robert Norman, writing of the endeavors of that time to determine the nature of magnetism, sets forth in quaint language the fact that the magnet's influence is not restricted to its surface, but extends well into space around it.

"Now, therefore, as I have before declared that diverse have whetted their wits, yea, and dulled them, as I have mine, and yet in the end have been constrained to flie to the stone (I mean God), who (to conclude) hath given vertue and power to this stone, proper in itselfe to shewe one certaine point by his owne nature, and not subject to anie other accident in Heaven nor in Earth, but freelie by his own proper vertue, received at His mightie hands in creation; and by the same vertue the needle is turned upon his owne centre. I mean the centre of his circular and invisible vertue pearcing all things and staied by nothing, bee it wall, boord, glasse, or anything whatsoever.

"And surely I am of opinion that if this vertue could by anie meanes bee made visible to the eie of man, it would be found in a sphericall forme extending round about the stone in great compasse, and the dead bodie of the stone in the middest thereof, whose centre is the centre of the aforesaid vertue."

The "vertue" *has* been made visible, and not only this, but its strength measured and the direction in which it is exerted, determined for every point of the region of its influ-

ence; the form, too, or bounding surface of the region has received a kind of hazy definition: it partakes much of the shape of the magnetic body itself—round, when that is a sphere—ellipsoidal, when it is elongated.

It is *in* the magnetic field that the effects of its kernel—the magnetized body—are experienced; this field, therefore, is of the utmost importance, and will be treated with the variety of illustration it requires.

By the magnetic field, is meant specifically a portion of the ether immediately surrounding a magnetized body of any kind—a region in which an abnormal condition is manifest; perhaps a strain somewhat like that of a tense spring, created by the magnetic body: and as the spring cannot be pulled into a tense condition from one end only, but must be held or fastened at the other end, and hence suffers strain throughout all its convolutions, so the stress in the ether is conveyed on and on from the vicinity of a magnet to some other point where it becomes opposite in direction: if the stress is outward from the north pole of a magnet, it must be inward at

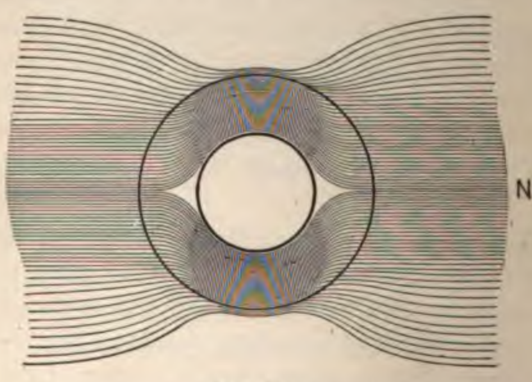


FIG. 221.

the south pole, in order that the lines of force between them exist at all. The stress becomes less and less as we recede from the poles, and at no great distance becomes too small

to measure with our instruments; and so we define that as its boundary limit; but this is true only to our senses.

It is the magnetic field that acts inductively upon all iron coming into its midst and excites in it the magnetic condition: even more, iron being the most permeable substance to such a field, the lines of force gather in upon it in preference to going through air. Let Fig. 221 represent the cross-section of a massive tubular body, such as a gun-turret or conning tower, then the terrestrial magnetic flow will concentrate upon it from without, pass onward through the iron, and emerge into air again, leaving the interior free of flow: thus a compass placed inside is deprived of its natural directive force, and becomes listless, if not entirely useless.

Fields of influence exist not only around steel magnets, but also around electromagnets, around wires carrying currents, and around bodies charged statically with electricity; and these various fields mutually react upon each other: this points to an intimate relationship between these several electromagnetic manifestations.

The magnetic field, in fact, is only one instance of a sphere of influence that is proper to every phenomenon in nature: a sounding body becomes less audible as we recede from it, until at length a point is reached where it is not heard at all; a source of light grows dimmer with distance, and eventually vanishes from view; the heat of a stove can be felt only within a certain radius; the electrifying effects of a charged body are limited to a specific region about it; chemical action is restricted to atomic spaces; and even the influence of person is of most avail only by actual presence—the absent are easily ignored.

174. Various methods of exploring the magnetic field. —The most striking means of portraying the magnetic field is by fine iron filings strewn on a sheet of paper above the magnet; they group themselves into delicate filaments that delineate every feature of the field: these are the lines of force

made visible—Fig. 222—and they are the same whether the magnet be a steel bar, a cylindrical coil alive with current, or two spheres charged with opposite electricity.

Each mote of the iron dust is itself a magnet, with minute foci of strength and a neutral zone as well defined as in the

FIG. 222.

largest magnet, and the tracery they form on the paper is caused by the attraction of dissimilar poles, north to south, in symmetrical alignment.

The picture exhibits a horizontal section through the field; but if the cut were in any other plane—either vertical or inclined at any angle—the structure and general aspect would be the same: the field is homogeneous in nature and ellipsoidal in form.

The magnetic field can also be surveyed with small needles, one free to move in Variation, the other in Dip, and the indications of both mapped into two views—a horizontal plane and a vertical section. Let *M*, Fig. 223, represent a magnet laid flat on the table, and the numbers around it, stations to which a small variation-needle is successively carried: at each, it points toward the nearest pole, and in the middle is parallel to the bar. If a third, a fourth, and other outlying series of stations be occupied, the needle would indicate the same symmetry of direction until a distance were

reached where the magnet's power was no longer felt, and that is said to be the limit of the field.

It is evident that if the magnet be turned on edge so that the side that was up become vertical, and the variation-needle be replaced by an equally small dip-needle, the deflections of

FIG. 223.

the latter would be similar to those of the former, and we should thus get a view of the vertical section.

It is also evident that if, in addition to being laid flat and set on edge, the magnet's surroundings could be examined in planes through its axis, but inclined successively at greater angles to the vertical, the results would differ in no wise, *in kind*, from those of corresponding stations in the horizontal and vertical planes. In other words, we should find the ether symmetrically stressed all round the magnet. The exploring needle in reality indicates a tangent to a line of force, and if such lines in any plane were prolonged, they would present the aspect of Fig. 222.

The strength of the field at the several stations could be ascertained by oscillation experiments, and thus we should have determined the Magnetic Elements of the bar—its Variation, Dip, and Intensity.

It is by methods entirely analogous that the magnetic field of the Earth has been explored: to many points of its surface, Variation compasses, Dip circles, and Oscillating

... and when the results ...cal with those of the ... strength in each hemi- ... variation converged like ... manner of parallels, were ... separated from those of ... curves of less and less In- ...e. True, all these have ... their prototypes in the ... represent the condition ... the diverse agglomera- ... uniform composition of a

... will be shown by a pro- ... which in no wise differs in ... 'ar and the Earth: the ... its variety of make-up ... the features of a mag-

...gnets is probably a com- ...ge of it may readily be ... in whose field a small ... along the lines Ns' and

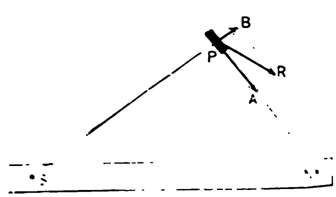


FIG. 225.

Ss. By shortening the ... Nn', Sn' and Ss', may ... until eventually they ...nes, as in Fig. 225, ... for diminished attrac-

tion between N and s' because of the repulsive effect of N upon n'; and the other for diminished repulsion only between S and s' because of the attractive effect of S upon n': and thus, as in Fig. 225, we have only two forces to consider— PN, attractive; and PS, repulsive.

The point P being anywhere in the field, it will be shown later that the force acting upon it varies inversely as the square of the distance from the foci N and S; that is, if $\overline{NP} = \frac{1}{2}\,\overline{SP}$, then the attraction at P is 1 and the repulsion $\frac{1}{4}$: laying off PA equal to 1 and PB equal to $\frac{1}{4}$, according to any scale, and completing the parallelogram, its diagonal $\overline{PR}$ is the resultant and indicates the direction of the needle, that is, a tangent to a line of force: and by such means the lines of force for the whole field may be drawn, and a reproduction of Fig. 222 obtained in its entirety.

The field of any particular magnet has certain features common to all magnets, whatever their form, and the matter will be further illustrated by an account of an investigation of one by Prof. Airy and Mr. Carpenter of the Greenwich Observatory. The cuts have been drawn from a description of the procedure, and are intended merely to illustrate the principles involved. In Fig. 226, A is a table on which a stand B, 1.8 inch high, may be set. Before beginning the experiment, the Earth's magnetism was completely neutralized by large magnets, so that a compass C, with needle one inch long, was entirely devoid of direction on every part of the table. A large sheet of paper was fastened on top of the table and an outline of the magnet M drawn upon it; around this the sixty-eight stations of Fig. 223 were accurately and symmetrically located. The bar M, 14 inches long, 1.4 inch wide and 0.35 inch thick, was then placed within its contour line; it had been magnetized many years, and was in a stable condition.

Observations were made with the magnet in two positions —flat, and on edge, and they were conducted as follows: the compass was set at each station, and a circle scribed about its

box; the ends of the needle were marked by two dots on the paper, and when the box was removed, these were joined by a delicate line, which gave the axis of the needle, that is, the direction of a line of force at that station.

The intensity of this force was determined by balancing it against a constant one—that of a horseshoe magnet, and

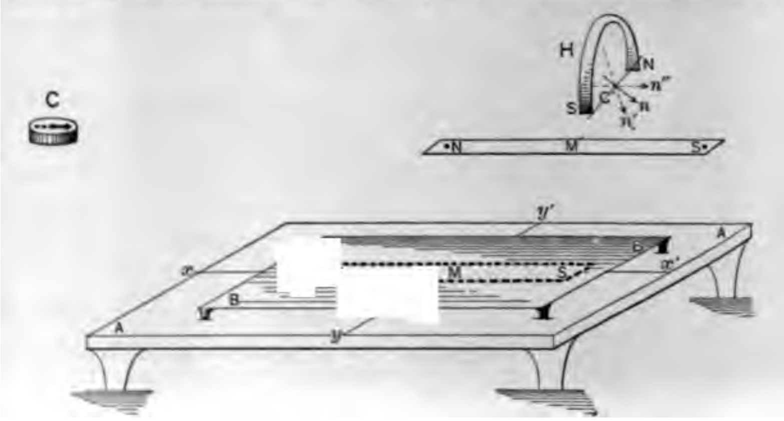


FIG. 226.

the method was this: in Fig. 226, *M'* is the magnet, and *C'* the small compass; its needle will point in the direction *C'n*, under the influence of *M'* alone; now bring down the horseshoe magnet *H*, vertically, until its poles are at a specified distance from the needle and transverse to its axis; the needle will take a new direction—*C'n'*; interchange the position of the poles of the horseshoe, and the needle will take another direction —*C'n''*; the mean value of these two angles of deviation is the deflection. The stand *B* was set on the table above the magnet *M*, to rest the horseshoe on, and the deviations were found by marking dots, as before, on the paper, at the ends of the needle. The cotangent of the resulting deflection at each station gave the force of *M* at that point. This becomes evident from Fig. 227: *M* is the magnet, *CA* the direction of the needle under its influence alone, and *CB* its direction balanced

between M and the horseshoe HH'; the length of the side CA may be taken to represent the strength of M, which alone is variable in different parts of the field, and $\overline{AB}$ the strength of the horseshoe—a constant; ACB is the deflection: then

$$\cot ACB = \frac{CA}{AB}, \text{ whence } CA = \overline{AB} \, . \cot ACB.$$

By having a circle on transparent material graduated to cotangents, and laying it down on the deflection at each sta-

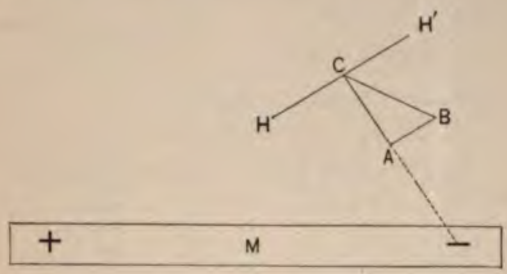


FIG. 227.

tion, the force was read off at once; and the mean of the resulting figures at corresponding symmetrical stations are given in Table 23—values of the large magnet's force.

These were resolved longitudinally and transversely to the magnet M, by constructing on each as hypothenuse, a right-angled triangle whose sides were the components sought: these are given in Table 24 for points whose coördinates have the center of the magnet for their origin.

When the large sheet of paper was removed from the top of the table A, it exhibited in short delicate lines the directions of the needle at the several stations; the paper was then folded along its axis xx', Fig. 226, and held against a window-pane so that the lines on each half were clearly visible; as they were symmetrical on both sides of the magnet, they should coincide; when such was not the case, a line was drawn midway between them as the mean direction; the paper was then

unfolded, and again doubled—this time on the axis *yy'*, Fig. 226, and the previous operation repeated: the mean of these directions are those given in Fig. 223 as the direction of the

TABLE 23.

MAGNETIC FORCE OF A LARGE MAGNET *M*, FIG. 223, AT THE POINTS OR STATIONS IN ITS FIELD DENOTED BY THE NUMBERS AROUND IT.

Numbers of the Stations.					Position of the Magnet *M*.	
					Presenting its *Edge* to the Station.	Presenting its *Flat Side* to the Station.
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1		*16*			274	250
2	15		17	30	326	293
3	14		18	29	408	363
4	13		19	28	566	480
5	12		20	27	678	542
6	11		21	26	622	480
7	10		22	25	513	454
8	9		23	24	600	584
31		*50*			160	160
32	49		51	68	163	165
33	48		52	67	191	183
34	47		53	66	224	200
35	46		54	65	235	217
36	45		55	64	211	197
37	44		56	63	193	180
38	43		57	62	175	173
39	42		58	61	181	177
40	41		59	60	201	193

needle at the several stations, that is, the direction of the force of the magnet.

It will be seen that they converge toward two points—each one-twelfth ($\frac{1}{12}$) the length of the bar from its end, and these are the poles. Tables 23 and 24 are instructive as showing the varying strength of the field.

In addition to the foregoing methods of tracing the lines of force, they may also be made both luminous and audible. Let a large electromagnet be alive with a powerful alternating

current, and its intermittances will fill the surrounding space with ether waves, which, if traversed by a small coil connected to a telephone, will actuate this into a variable hum

TABLE 24.

LONGITUDINAL AND TRANSVERSE COMPONENTS OF THE MAGNETIC FORCE.

[Cols. (6) and (7) of Table 23], with the Coördinates of the Points of the Field for which the Force is given, the Center of the Magnet *M*, Fig. 223, being the Origin of Coördinates.

Coördinates of Station in Field.		Position of the Magnet *M*.			
		Presenting its *Edge* to the Station.		Presenting its *Flat Side* to the Station.	
Longitudinal Ordinate.	Transverse Ordinate.	Longitudinal Force.	Transverse Force.	Longitudinal Force.	Transverse Force.
0.0	2.2	− 274	0	− 250	0
1.4	2.2	− 283	+ 161	− 260	+ 137
2.8	2.2	− 262	+ 315	− 236	+ 276
4.2	2.2	− 198	+ 530	− 182	+ 444
5.6	2.2	− 56	+ 678	− 36	+ 540
7.0	2.2	+ 216	+ 585	+ 158	+ 451
8.08	1.76	+ 367	+ 360	+ 325	+ 315
8.5	0.7	+ 580	+ 166	+ 552	+ 184
0.0	3.7	− 160	0	− 160	0
1.4	3.7	− 147	+ 73	− 149	+ 72
2.8	3.7	− 127	+ 142	− 123	+ 136
4.2	3.7	− 88	+ 205	− 79	+ 185
5.6	3.7	− 19	+ 235	− 12	+ 217
7.0	3.7	+ 49	+ 205	+ 51	+ 190
8.13	3.5	+ 95	+ 167	+ 92	+ 154
9.12	2.8	+ 129	+ 122	+ 124	+ 118
9.79	1.84	+ 159	+ 88	+ 157	+ 82
10.0	0.7	+ 199	+ 42	+ 190	+ 40

that strikes the ear: or, if the coil be connected to a little incandescent lamp, this will glow and fade as the furrowed ether field is crossed, and thus give ocular evidence of its condition.

175. The features of the magnetic field produced in air and water.—The view taken of the electromagnetic phenomena with which this Treatise is especially concerned, is that they are due to waves of the ether of space; that these

waves are caused by vibrations of the atoms of matter; that the same atom has different vibrations, just as a tense piano-wire vibrates as a whole and also in sections of varied length, giving out the fundamental note and its harmonics; and that these several vibrations of the atom give rise to waves that produce heat, light, and chemical action, as well as electromagnetic effects.

Numerous facts have been cited to show both the existence of the ether and the waves in it: another may be added to the number—communication by wireless telegraphy.

That a little instrument, under the motive power of an electric current, can, without visible connection, affect another instrument miles away, through fog and rain and driving gale, and even through the dense rock of mountain range, and this by sympathetic movement *only*, when the second instrument is attuned to the first and the waves fall upon it, like the timed impulses upon a swing, before it will respond in intelligible language—that this can be done and is an accomplished fact, over a hundred miles of distance, is truly as good proof of the existence of a medium for the electric impulse as that vocal vibrations require air for their transmission.

The air will not respond to the electric voice, and if moving as the hurricane, will not *interfere* with it; so that another medium must intervene; and waves other than its own—even in the ether—will not affect an electromagnetic instrument: the actinic ray, the ray of light, or the ray of heat might beat forever on a galvanometer without turning its needle from the meridian; but let a dynamo begin molding the ether into waves that proceed along a wire, and at once the needle swings from rest and acquires a permanent deviation.

Water, air, and glycerine are but fluids of differing density, and perhaps the ether of space is a fluid also; and air, water, and glycerine around pulsating bodies acquire an abnormal condition whose features are identical with those of

the stressed ether about electric and magnetic bodies. The water is clearly before our eyes, and its condition is the result of mechanical movement at our hands; but the ether and the method of producing its stressed state are not within the scope of experimental demonstration: yet when the results in the one and the other are the same, it is but fair to infer that their causes may also be identical.

The means by which bodies are made to vibrate in fluids will now be described; the conditions thereby produced, occupy, probably, the lower round of a ladder at whose top such phenomena as the stressed state of ether around electric and magnetic bodies may be found—extremes of gradation, not differences in kind.

A vibratory motion of an atom or body is one in which its bounding surface changes form: it is a quivering of the substance. A bell vibrates while emitting its decadent notes, for they are due to an inward and outward movement of the rim.

It is conceivable that a change of form may take place variously, and thus give rise to different kinds of waves in the medium.

Pulsating and vibrating are equivalent terms, but oscillating is a different motion—it is a to-and-fro movement of the body *en masse*, like a pendulum: a blow to the latter while oscillating will set up vibration in its particles.

The experiments about to be described, were made by Prof. Bjerknes and Mr. Stroh, and the particular form of pulsating body used was a little drum with elastic rubber heads—Fig. 228.

Two such drums are pulsating in the same phase when both expand or both contract together, as in Figs. 229 and 230, Plate M; and in opposite phase when one is distending while the other is drawing in, Figs. 231 and 232: and similarly with oscillating bodies when moving as indicated by arrows beneath the balls in Figs. 233, 234, 235, and 236, Plate M.

It was found by these experiments that there is close

analogy between the mutual effects of pulsating and oscillating bodies on the one hand, and the reciprocal action of magnetic poles and of electrified bodies on the other; but with this qualification: in all cases, the mechanical result is the converse of the electromagnetic.

The law of variation of force in both the mechanical and electromagnetic fields is the same in all cases—inversely as the square of the distance.

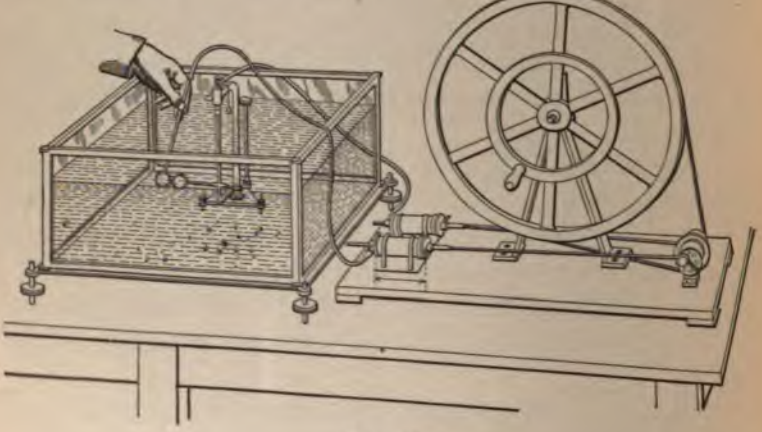


FIG. 237.

Fig. 237 represents the apparatus used in the experiments: two little drums (Fig. 228) are immersed in water, one held in the hand by a flexible tube that leads to a small air-pump, and the other fitted to the end of a delicate rod that has motion on a pivot, like a compass-needle; this drum also connects with another pump by a flexible tube; the pistons of both pumps are moved by a wheel with connecting-rods, as shown, and they are susceptible of such arrangement that the drums may pulsate in the same or opposite phase as desired.

When the drum in the hand is brought within the influence of the other, and both are pulsating in the same phase,

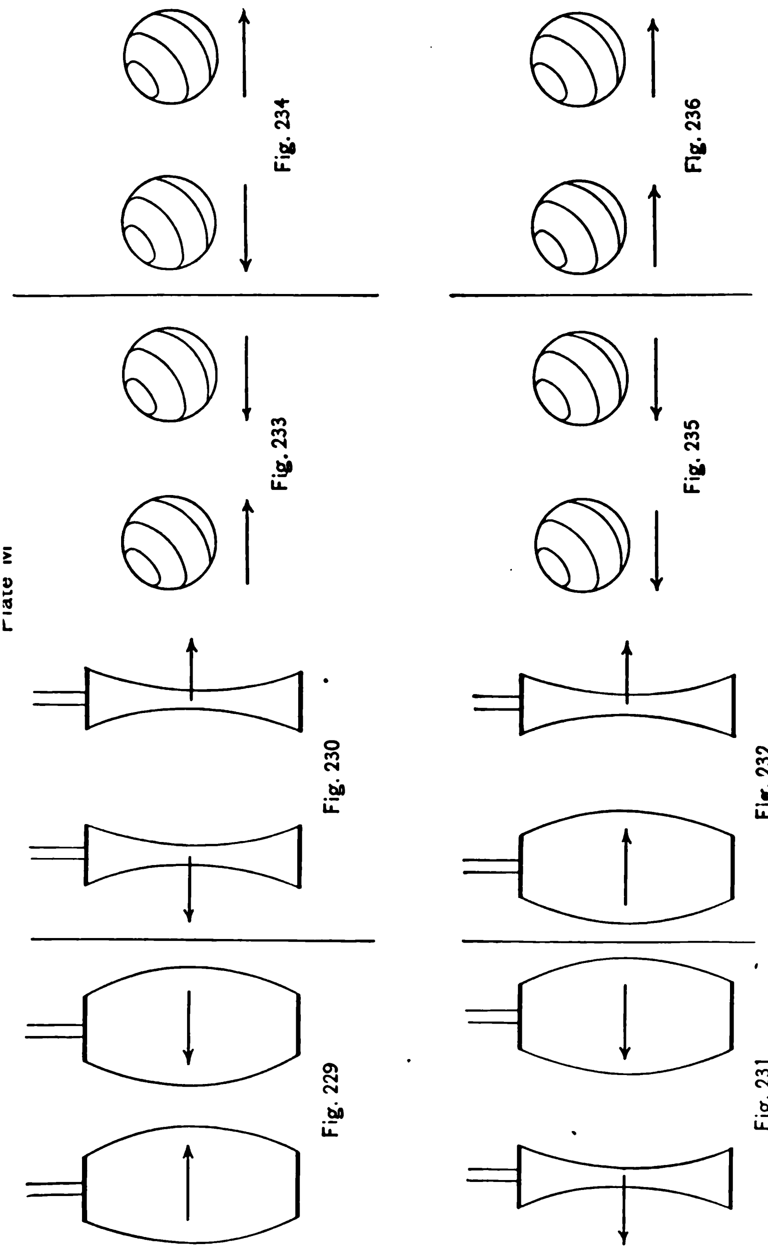


Plate IV
Fig. 229
Fig. 230
Fig. 231
Fig. 232
Fig. 233
Fig. 234
Fig. 235
Fig. 236

the pivot rum will move up to the hand drum—showing attraction; this is the converse of two similarly electrified bodies, or two like magnetic poles: on the other hand, when the drums are pulsating in opposite phase, the pivoted drum is repelled, which again is the converse of the electric and magnetic cases.

FIG. 228.

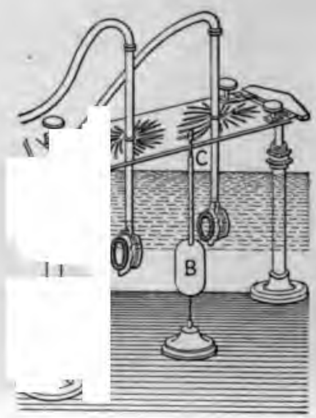


FIG. 238.

To depict the lines of force in the fields of pulsating bodies, another apparatus, Fig. 238, is used in connection with the trough of water and little pumps: it consists of a metal ball *B* supported on a pedestal by an elastic steel rod; wherever placed in the water, the ball oscillates along a line of force, that is, in the direction in which the waves raised by the pulsating body are moving; a fine wire with a camel's-hair brush at the end *C*, extends upward from the ball, and as this latter moves to and fro under the impulse of the waves, the brush—partaking of the motion—traces out the lines of force on the under side of a pane of smoked glass.

By such means the mechanical fields in water due to varied conditions of the pulsating bodies were delineated: they are represented by the odd-numbered drawings from Fig.

239 to 255, while the even-numbered drawings from Fig. 240 to 256 represent the magnetic and electric fields produced by corresponding conditions, formed by iron filings.

FIG. 239.

FIG. 240.

Fig. 239 shows the effect of a small bladder distending and collapsing, and Fig. 240 that of a single magnet pole—straight lines radiating from a center in both cases.

Fig. 241 exhibits the result of a single body oscillating

FIG. 241.

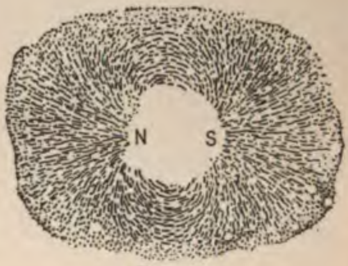


FIG. 242.

along a line corresponding to the axis of a magnet whose field is depicted in Fig. 242: both have radial lines from each end gradually curving toward arches on the sides.

Fig. 244 represents the field of two similar magnet poles, and Fig. 243 the effect of two bodies pulsating in the same phase, as in Figs. 229 and 230: the trains of waves caused by

both drums meet midway and are forced outward from a center exactly as the lines of iron filings are by mutual repulsion.

FIG. 243.

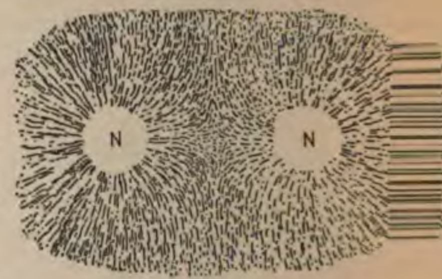


FIG. 244.

FIG. 245.

FIG. 246.

FIG. 247.

FIG. 248.

Fig. 246 shows the field of two poles of opposite name, and Fig. 245 that of two bodies pulsating in opposite phase, as in Figs. 231 and 232: as the faces of both drums are mov-

ing in the same direction at the same time, the trains of waves from them merely flow back and forth between them and radially outward elsewhere; and this, too, is perhaps the

FIG. 249.

FIG. 250.

movement of the ether that causes the iron filings to assume exactly similar curves.

Figs. 247 and 248 exhibit a combination of the effects

FIG. 251.

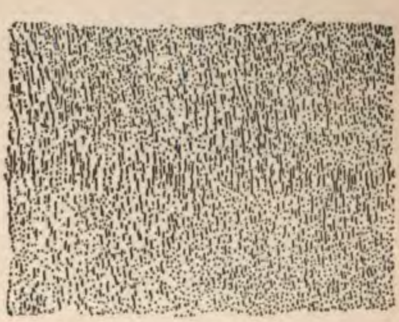


FIG. 252.

shown separately in the four preceding figures—two magnetic poles of the same name and one of a different name contrasted with two bodies pulsating in the same phase and one in opposite phase: the lines of force in both cases are identical.

Figs. 249 to 256 represent analogies between oscillating

both [illegible] and the experiments were per- center [illegible] such as glycerine. Fig. 250 repre- sion [illegible] and Fig. 249 that about a cylin- [illegible] axis like the balance-wheel of a

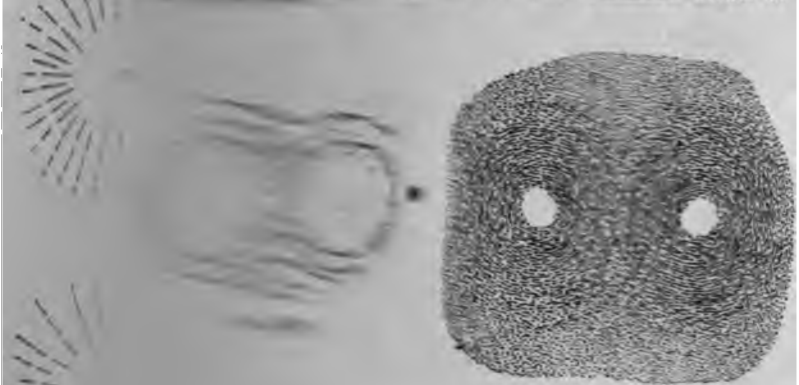


FIG. 254.

[illegible] and cylinder being perpendicular to [illegible] in both cases the lines of force form [illegible] the moving surfaces. Figs. 251 and [illegible] conditions to the preceding, except that [illegible] to the moving surfaces; and [illegible] of force are parallel to these sur-

[illegible] fields of two currents and two [illegible] plane of the paper: the cur- [illegible] direction and the cylinders oscillate in [illegible] connected by a belt; and the similarity of

[illegible] field of two currents running in op- [illegible] parallel, and Fig. 255 that of two cylin- [illegible] opposite ways, as if connected by cog- [illegible] and again the identity of the lines of

ar[illegible]

as [illegible] the ether of space only

in density and viscosity—by a long stride, to be sure, but still a step through stages of matter—have been produced lines of

FIG. 255.

FIG. 256.

force that are identical with those excited in the ether by magnetic and electric means: vibrating and oscillating bodies of bulk and weight gave rise to the abnormal conditions in the gross fluids, and it is quite possible that similar motions of *atoms* cause the same in the refined ether.

The effects of pulsating bodies in air will now be de-

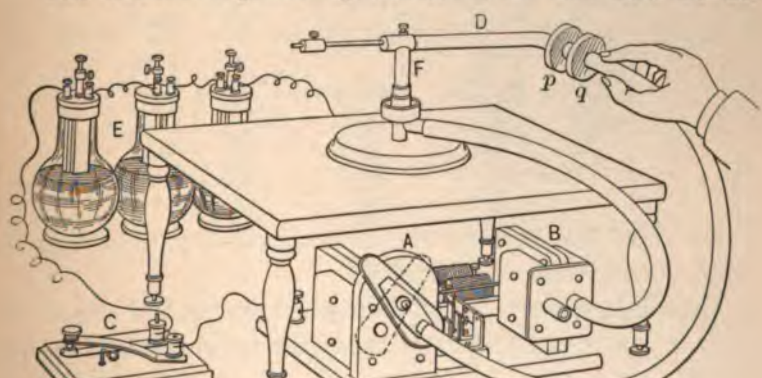


FIG. 257.

scribed. Fig. 257 represents the apparatus used: it consists essentially of two air-pumps which may be actuated by an

electric current in such way that either like or unlike phase of two pulsating drums is produced at will. The air-pumps are at *A* and *B* beneath the table, and the battery *E* supplies the current which is controlled by the keyboard at *C*. Flexible tubes lead from the pumps and convey air to the little drums *p* and *q*: upon the table the tube *D* has one of these drums at its end, the tube being pivoted at *F* so as to have free motion in a horizontal plane. When the pump connections are so arranged that air is forced out or sucked in, in both drums at the same instant, producing the condition of their elastic heads seen at *m* and *n*, Fig. 258—that is, same phase—this will give rise to attraction between the drums, and if *q* is held in the hand, *p* will move up to it even from some little distance; but when arranged so that one drum-head is bulged out coincidently with the other being drawn in, as at *h* and *k*, Fig. 259—that is, opposite phase—this will

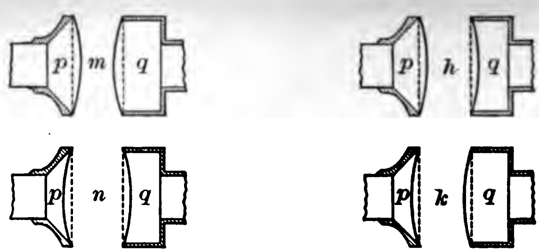


FIG. 258. FIG. 259.

cause repulsion between the drums, and if *q* be held in the hand, *p* will move away from it.

It will be observed that these phenomena, like the similar ones in water, are the converse of the magnetic and electric effects.

For further experiments in air, the apparatus is arranged as in Fig. 260, where the tubes are supported by rods in such way that the drums may be drawn apart to any desired distance.

A pulsating body creates waves in air just as in water, and the directions they take, indicate the lines of force: to

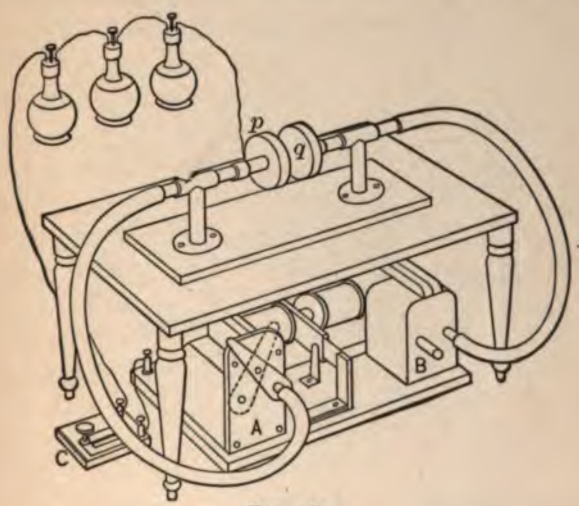


FIG. 260.

map them out, a small gas flame, Fig. 261, is used, as it will blow in the direction, and to the extent of the amplitude, of

FIG. 261.

the wave. By carrying such a flame all over the field affected by one or both of the drums of Fig. 260 when pulsating, and carefully observing and recording the motions, the three Figs., 262, 263, and 264, were obtained: the first is from a single membrane; the second from two, pulsating in the same phase; the third from two, in opposite phase: and the identity of all with the fields around magnetic poles is apparent.

It is a curious fact that a little vane, Fig. 265, with two wings will come to rest in every case at right angles to the

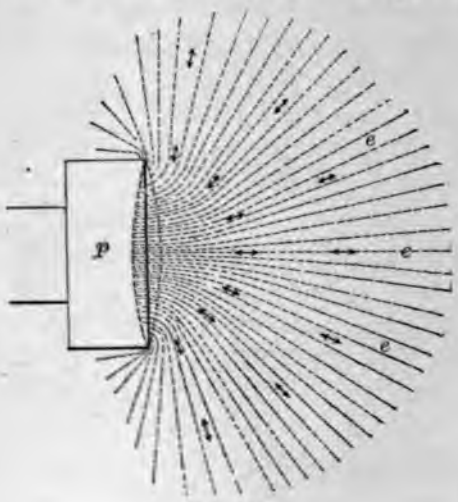


Fig. 262.

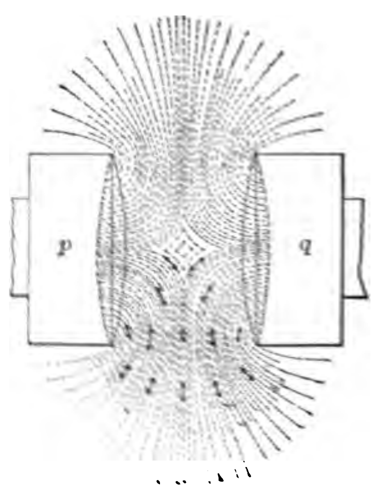


Fig. 263.

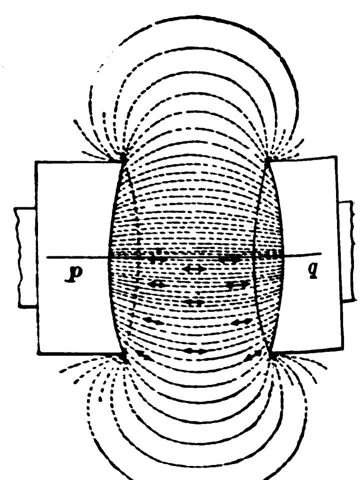


Fig. 264.

lines of force: this is another means of mapping them out, as is shown by Fig. 266—fields produced by the pulsating drums

Fig. 260, and in which, again, we find the same features
it have already been depicted.

In order to compare the field of air, Fig. 266, with a field
ether under magnetic strain, the apparatus of Fig. 267 was

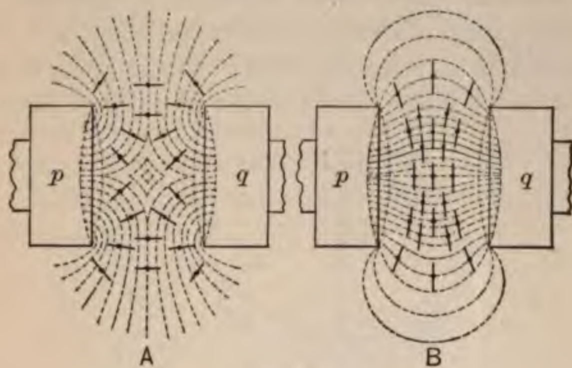


FIG. 266.

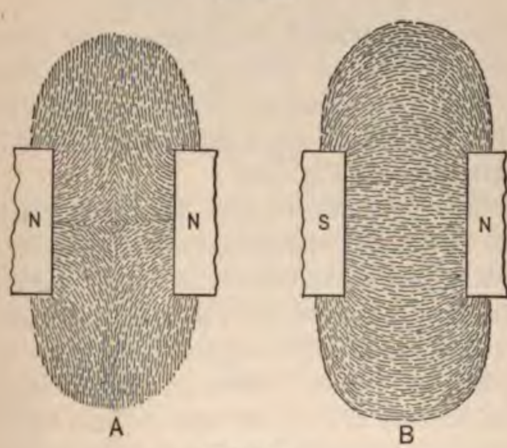


FIG. 268.

ed: it consists of two electromagnets whose pole ends are
same size as the pulsating drums of Fig. 260; like those,
y can be drawn apart to any distance, and, by means of a
itch-board, can be converted into poles of like or unlike

name to correspond with the drums in like or unlike phase. Thus there is complete analogy between the two instruments (Figs. 260 and 267), the first to produce trains of waves in air by visible pulsating membranes, and the second, waves in the hypothetical ether by the assumed vibration of atoms. To make this magnetic field visible, a card was cut to the outline of the space between the poles of the magnets and placed in the horizontal plane of their axes; iron filings were strewn

FIG. 265.

on this cardboard, and with the magnet alive and poles first of the same and then of different name, the characteristic fields, Fig. 268, were obtained: it will be seen that they are identical with the fields of air of Fig. 266 obtained by the mechanical instrument of Fig. 260.

Next, a little platform, *E*, Fig. 267, having a wire frame on which an iron disc *D* about a centimetre in diameter was suspended, was placed equidistant between the electromagnets, and the current turned on: when the poles were of same name, the disc stood at right angles to the axes of the magnets, and when of different name, parallel thereto—in both cases parallel to lines of force, as may be seen by comparison with Fig. 268. The action upon the iron disc to produce such results was of course electromagnetic induction.

Now placing the board *E* with its disc *D* between the pulsating drums of Fig. 260, the following is observed: when the drums vibrate in like phase the disc turns parallel to their axes, and when in unlike phase, at right angles thereto—that

is, in both cases across the aerial lines of force, as the little vane did, and the exact converse of the magnetic case, when the disc was placed between the live electromagnets, where it stood parallel to the lines of magnetic force.

The force which produces these effects is not the same in all parts of the field: between the membranes in unlike phase and the poles of contrary name—see *B* in both Figs. 266 and 268—the greatest directive force is in the center on the axis; while between membranes in like phase and similar poles—see *A* of both Figs. 266 and 268—the greatest force is near the circumference of drum and pole—in which both the mechanical and magnetical fields agree.

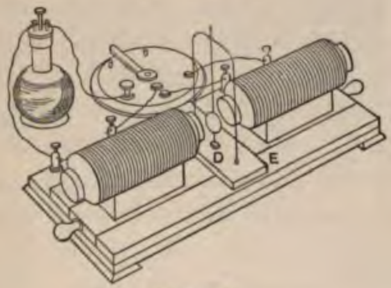


FIG. 267.

In the preceding experiments, the effect of two different rates of vibration of the pulsating membranes was tried, that is, one drum of the pair pulsating faster than the other per second; and in every possible combination of two different rates, only *attraction* resulted: therefore it would seem that the only conditions upon which *repulsion* can be had, are, that the vibrations of the two membranes be absolutely of the same rate per second, and that they be in opposite phase; and this would lead to the assumption that if magnetism is due to the vibration of some medium, the rate of vibration of that medium must be the same in all magnets, that is to say, one particular rate of vibration of the medium would constitute magnetism.

Thus, in air, water, and glycerine—three widely differing fluids—it has been shown that an abnormal condition arises around vibrating and oscillating bodies, and that this mechanical field bears the closest analogy in its features to the field of ether around a steel magnet or a cylindrical coil of wire alive with electricity: one more condition remained to be tested—the stress in the ether around a static charge on a body, and this has recently been done.

Upon a pane of glass fine mahogany sawdust was sifted to form an even layer: to the under side of the glass two circles of tin-foil were pasted and connected by wire with a Wimshurst machine. When one circle only was charged with either kind of electricity, the sawdust settled into radial lines exactly as iron filings do on a sheet of paper above one pole of a vertical magnet; when both circles were charged with the same kind of electricity, the sawdust assumed the characteristic curves of two magnet poles of same name opposed to each other; and when the charges were respectively plus and minus, the sawdust took form identical with the filings around a north and a south pole facing each other. The sawdust—apparently non-magnetic—behaves exactly like the intensely magnetic iron filings; and the question arises, Why? The flux from the magnets converts the particles of iron into so many minute magnets which join end to end and form the visible lines of force: and such, no doubt, is also the case with the grains of wood. Nearly all substances in nature are magnetic—variously, to be sure, and the gap between iron and wood, in the scale, is well shown by the avidity with which the filings of the one will line up, compared with the feeble movement of the grains of the other, which must be coaxed into shape by continued tapping of the glass.

176. Analytical investigation of the magnetic field.— Every experimental examination of a magnetic field— whether of a steel bar, an iron ship, or the terrestrial globe

—involves the employment of instruments whose chief part is a magnetic needle: this, too, has a field of its own, so that the procedure reduces to the action of one magnetic field upon another, and this action is the object of the mathematical inquiry.

The intensity of any point of a simple field due to one magnet will first be investigated; and then the complex field of two magnets and the Earth, with the magnets in both the broadside and the end-on position.

In Fig. 269, let P be any point in the field of the steel magnet NS: the magnetic intensity along a line of force being a stress in the ether, similar to the tension of a rubber band, its direction and amount may be represented by PR, from the positive toward the negative pole—the line a small needle would take at P if free to move horizontally; its components in the direction of the poles are Pn' and Ps'.

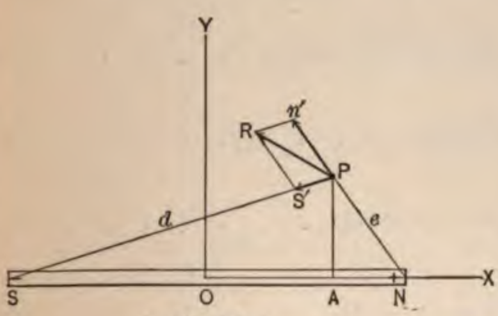


FIG. 269.

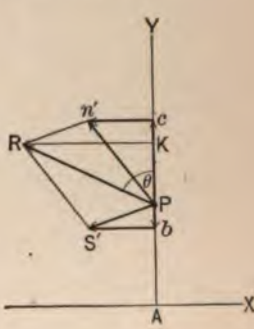


FIG. 270.

The center of the magnet being the origin of coördinates, those of P are $OA = x$ and $AP = y$.

If $2l$ be the exact length of the magnet, m the total intensity of each half, and M the *magnetic* moment of the bar, then

$$M = 2m . l. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

It will be shown that M can be determined in dynes, whence

$$m = \frac{M}{2l}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

that is, we can ascertain the strength of each pole in dynes.

As the strength of pole varies inversely as the square of the distance from it, we have for the intensity of each pole at P,

$$\frac{m}{d^2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and

$$\frac{m}{e^2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

By Fig. 269,

$$d^2 = \widehat{AP}^2 + \widehat{AS}^2; \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$e^2 = \widehat{AP}^2 + \widehat{AN}^2; \quad . \quad . \quad . \quad . \quad . \quad (6)$$

$$\widehat{AP} = y; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$\widehat{AS} = (x + l); \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and

$$\widehat{AN} = (x - l). \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

By projecting the components Ps' and Pn' on a parallel and a perpendicular to the magnet, as in Fig. 270, we form the triangles bPs' and cPn', similar to APS and APN, Fig. 269, respectively, since the corresponding sides are parallel; the angles of both sets of triangles are therefore equal and their trigonometrical functions the same.

To resolve a force, is to multiply it by the cosine of the

angle between its old and new directions; hence we have the following direction-cosines:

$$\cos ASP = -\frac{\widehat{AS}}{d} = -\frac{(x+l)}{d}; \quad . \quad . \quad (10)$$

$$\cos APS = -\frac{\widehat{AP}}{d} = -\frac{y}{d}; \quad . \quad . \quad . \quad . \quad (11)$$

$$\cos ANP = \frac{\widehat{AN}}{e} = \frac{(x-l)}{e}; \quad . \quad . \quad . \quad . \quad (12)$$

$$\cos APN = \frac{\widehat{AP}}{e} = \frac{y}{e}; \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and, therefore, multiplying (3) and (4) by these cosines, we have the resolved components:

$$\widehat{bs'} = -\frac{m \,.\, x}{d^3} - \frac{m \,.\, l}{d^3}; \quad . \quad . \quad . \quad . \quad (14)$$

$$\widehat{cn'} = \frac{m \,.\, x}{e^3} - \frac{m \,.\, l}{e^3}; \quad . \quad . \quad . \quad . \quad . \quad (15)$$

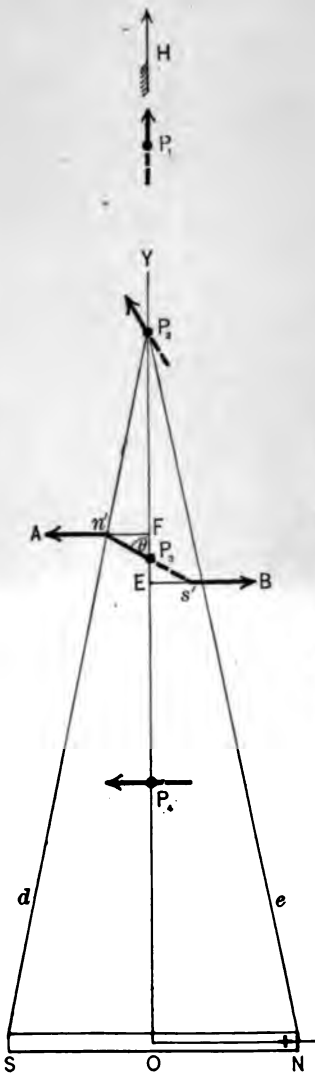
$$\widehat{Pb} = -\frac{m \,.\, y}{d^3}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

and

$$\widehat{Pc} = \frac{m \,.\, y}{e^3}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (17)$$

The sum of (14) and (15) gives the whole force in the axis of X, and of (16) and (17) that in Y; that is,

$$X = \widehat{RK} = -m.x\left(\frac{1}{d^3} - \frac{1}{e^3}\right) - m\,.\,l\left(\frac{1}{d^3} + \frac{1}{e^3}\right); \quad (18)$$



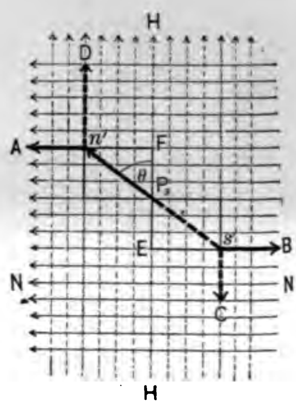


FIG. 273.

FIG. 271.

$$Y = \widehat{PK} = -m.y\left(\frac{1}{d^3} - \frac{1}{e^3}\right); \quad . \quad . \quad . \quad . \quad . \quad . \quad . \tag{19}$$

$$R = \sqrt{\widehat{RK}^2 + \widehat{PK}^2} = PR = \sqrt{X^2 + Y^2}. \quad . \quad . \quad . \tag{20}$$

Let $RPK = \theta$, the angle the resultant makes with the axis of Y; then

$$\tan\theta = \frac{\widehat{RK}}{\widehat{PK}} = \frac{X}{Y} = \frac{x(e^3 - d^3) + l(e^3 + d^3)}{y(e^3 - d^3)}. \tag{21}$$

Equations (18) to (21) determine completely, for any point of the field, the components of the intensity parallel and perpendicular to the magnet, and their resultant value and its direction.

If $d = e$, or the point P is on the axis of Y, Fig. 271, we have from (19) and (21), $Y = 0$, $\tan\theta = \infty$, hence $\theta = 90°$; and from (18),

$$X = -\frac{2m.l}{d^3} = -\frac{M}{d^3}, \quad . \quad . \quad . \quad . \tag{22}$$

which alone is the intensity of the field; by means of (5), (7), and (8), this becomes

$$X = -\frac{M}{\{y^2 + (x+l)^2\}^{\frac{3}{2}}} = -\frac{M}{(y^2 + l^2)^{\frac{3}{2}}}, \quad . \tag{23}$$

since $x = 0$, P being on the axis of Y.

If the point P is on the axis of X, then $y = 0$, and equations (19) and (21) become $Y = 0$, $\tan\theta = \infty$ $\therefore$ $\theta = 90°$; and we have as before, equation (18) for the sole value of the intensity; in this case, Fig. 272,

$$d = (x + l), \quad . \quad . \quad . \quad . \quad . \quad . \quad . \tag{24}$$

and

$$e = (x - l); \quad . \quad . \quad . \quad . \quad . \quad . \quad . \tag{25}$$

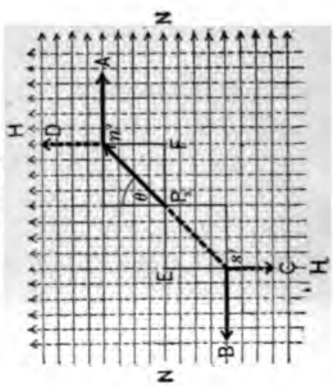


FIG. 274.

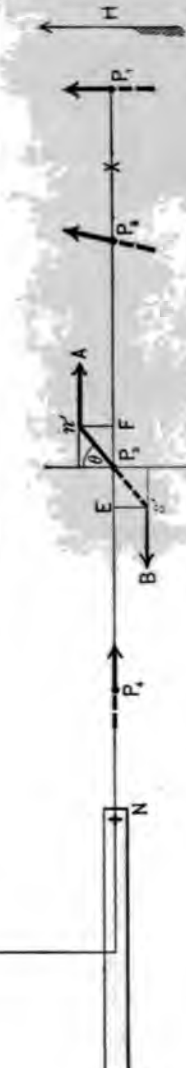


FIG. 272.

d and e being as before the distances from the ends of the magnet NS to the point P.

Then writing (18) in another form, and substituting the values of (24) and (25), we have:

$$X = -\frac{m \cdot x}{(x+l)^3} + \frac{m \cdot x}{(x-l)^3} - \frac{m \cdot l}{(x+l)^3} - \frac{m \cdot l}{(x-l)^3}$$

$$= -\frac{m(x+l)}{(x+l)^3} + \frac{m(x-l)}{(x-l)^3}; \quad \ldots \ldots \quad (26)$$

or

$$X = -\frac{m}{(x+l)^2} + \frac{m}{(x-l)^2}$$

$$= -m\left\{\frac{1}{(x+l)^2} - \frac{1}{(x-l)^2}\right\} = \frac{2Mx}{(x^2-l^2)^2}. \quad (27)$$

If the point P, while on either axis, be very distant, that is, if y in Fig. 271 or x in Fig. 272 be so great that l may be omitted beside it, then (23) and (27) reduce to:

$$X = -\frac{M}{y^3}, \quad \ldots \ldots \quad (28)$$

and

$$X = \frac{2M}{x^3}, \quad \ldots \ldots \quad (29)$$

from which it is seen that the end-on position is twice as powerful as the broadside, P being equally distant in both cases from the center of the magnet.

Now, let a short needle be placed in the axes of X and Y, Figs. 272 and 271: at P_1 it is outside the magnet's controlling field; on entering within the influence of this, it will be deflected until it becomes parallel to the magnet at P_4. Let $2l'$

be the length of the short needle and m' the magnetic intensity of each half; then its magnetic moment is

$$M' = 2m'.l' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (30)$$

The effort of the magnet NS is merely directive—parallel to the axis of X; it may be represented by two equal and opposite forces $\widehat{n'A}$ and $\widehat{s'B}$ as in position P_3 of the needle, and its value is given by (23) and (27): the *torque*, or tendency to turn the needle, is obtained by multiplying together the intensity m', the force $\widehat{n'A}$, or $\widehat{s'B}$, and the perpendicular distance between these; that is,

$$m'.\widehat{n'A}.\widehat{EF}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (31)$$

for Fig. 271, and

$$m'.\widehat{n'A}(n'F + Es'), \quad . \quad . \quad . \quad . \quad (32)$$

for Fig. 272. In the former we have

$$\cos\theta = \frac{\widehat{P_3F}}{\widehat{P_3n'}}, \therefore 2\widehat{P_3F} = \widehat{EF} = 2\widehat{P_3n'}.\cos\theta = 2l'\cos\theta, \quad (33)$$

whence, substituting in (31) the value of $\widehat{n'A}$ given by (23) and that of EF from (33), we have for the torque of the magnet NS upon the needle $n's'$,

$$\frac{2m'.l'.M.\cos\theta}{(y^2 + l^2)^{\frac{3}{2}}} = \frac{M'.M.\cos\theta}{(y^2 + l^2)^{\frac{3}{2}}} \quad . \quad . \quad . \quad (34)$$

for the broadside position, and similarly from (27) and (32),

$$\frac{2xM'M\cos\theta}{(x^2 - l^2)^2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (35)$$

for the end-on position.

Finally, introduce the effect of the terrestrial field. Its directive power in both cases is at right angles to the magnet's length, and at P_1 alone controls the needle, while at P_4 the magnet alone controls: between these points the needle is variously deflected—balanced between two couples.

Figs. 273 and 274 are enlarged views of the contending fields at P_3—represented by parallel lines to denote their uniformity, as each would be in a very small area, if the other were not injected into it. The effort of the Earth upon the needle is directive, and may be represented by two equal and opposite forces, $\widehat{n'D}$ and $\widehat{s'C}$—each denoted by H at the point P_3: the torque here, as with the magnet, will be given by the product of the intensities of the forces and the perpendicular distance between them; that is,

$$m' . \widehat{n'D}(\widehat{n'F} + \widehat{Es'}), \quad . \quad . \quad . \quad . \quad . \quad (36$$

for Fig. 273; and

$$m' . \widehat{n'D} . \widehat{EF}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (37)$$

for Fig. 274. In the first,

$$\sin\theta = \sin n'P_3F = \frac{\widehat{n'F}}{\widehat{P_3n'}}, \quad . \quad . \quad . \quad . \quad (38)$$

but

$$\widehat{n'F} = \widehat{Es'}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (39)$$

and

$$\widehat{P_3n'} = \widehat{P_3s'}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (40)$$

whence

$$(\widehat{n'F} + \widehat{Es'}) = 2\widehat{n'F} = 2\widehat{P_3n'} \sin\theta = 2l' \sin\theta. \quad . \quad (41)$$

Substituting in (36) the value of $\widehat{n'D} = H$, and that of

(41), we have
in both Figs.

Thus, for ever
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$$\frac{M'M\cos\theta}{(y^2 + l^2)^{\frac{3}{2}}}$$

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$$\frac{2xM'M\cos\theta}{(x^2 - l^2)^2}$$

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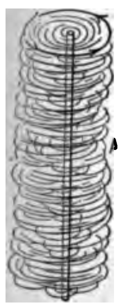
gather into concentric rings—lines of force. Consider a group of such rings—Fig. 277: if the current flow down as at *W*, there will be apparent motion in each ring in the direction of the arrow at *m*; if the current flow up, the direction at *m* will be reversed: in both cases, if a north or south pole



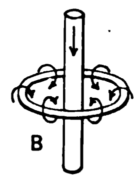


FIG. 275.

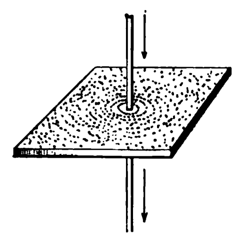


FIG. 276.

could exist alone, it would seem that it should be carried round and round the wire in a closed curve, but as the poles cannot be separated in any magnetic body, one is urged forward, the other backward, and thus only a directive power is exercised on the needle—it takes the line of a tangent to the curve, its north pole pointing in the direction the hands of a clock move, if the current be down; but in the contrary direction, if it be up.

Every fluctuation, or break, in the current causes a change in the lines of force *f*, Fig. 277. It has been shown elsewhere in this book that the primary condition of a current is a series of minute pulses; from these arise in the ether a succession of ripples that travel outward from the conductor: the more frequent the pulse, the more nearly uniform the current, and the closer the ripples, thus forming an almost even field; but when a rapid break-circuit is introduced, the successive interruptions of the current give rise to waves in

the ether, as in Fig. 278. This expanding movement—ripple or wave—at right angles to the wire is the magnetic constituent of the field, the motion of the ether that makes wireless telegraphy possible.

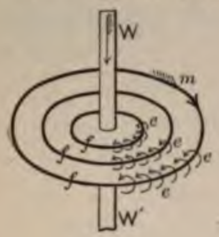


FIG. 277.

FIG. 278.

FIG. 279.

But there is also an electric constituent, for the field is electromagnetic. The discharge of a gun of a ship's battery sometimes sends a ring of smoke through the air; and a puff from a cigar will do the same: these are vortex rings—Fig. 279—and of such the field around a live-wire may be conceived to be made up.

Each line of force *f*, Fig. 277, is the core of a whirl *e*, just as a circle of wire may be the axis of a string of beads, all rotating upon it.

"It is conceded that in every electromagnetic field the ether is in a rotary motion both about a magnet and a wire carrying a current. The rotation of an electric arc in a magnetic field shows it, and the twist given to a polarized ray of light passing through it also shows it. The twist given to a conductor through which a current is flowing also gives direct evidence of the same condition." (Prof. Dolbear.)

Now consider the effect of rotation upon a quantity of water: in Fig. 280 a vertical section of a little vessel is represented; the top and bottom are of thin wood and the sides of elastic rubber; it is filled with water and connected by a band with a wheel for whirling it.

When set in rapid motion, it flattens as in Fig. 281, creat-

ing a tension in the direction of its length as is shown by drawing up a weight; and if two such vessels rotate near each

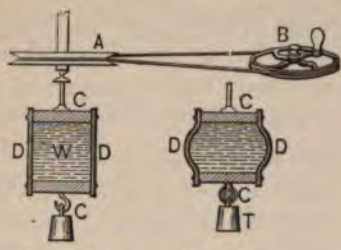


FIG. 280. FIG. 281.

other, their bulged sides will push each other away. Compare a series of these little rotating vessels with the whirls *e* strung

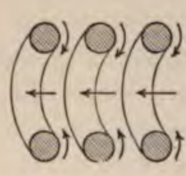


FIG. 282.

FIG. 283.

along the line of force *f*, Fig. 277, and it will be seen how there can be tension along the circle *f*, and repulsion between every two such circles in the same plane. The vortex ring as a whole has a field of influence—one face attractive, the other repellant; and if in a series of them, the *un*like sides look toward each other, as in Fig. 282, the individual effort is augmented and transmitted; but when *like* sides look at each other, as in Fig. 283, repulsion alone takes place.

Now, conceive the field of a live wire made up of myriads of vortex rings arising in the quiescent ether from point to point with the velocity of light, through some action of the source of electricity; and consider their dissimilar sides all

facing each other, as head to tail in a series of coins strung along a cord through their centers: then we should have the electric tension along the axes of the rings (or coins) parallel to the conducting wire, that is, the pull or strain that gives motion to the street-car; while spreading out into space are the undulations, from column to column of the vortex rings, that produce magnetic effects, as in the case of wireless telegraphy: both combined—the onward and outward movement, constitute the electromagnetic wave.

It is evident from this conception that the electric constituent is not restricted to the wire, but that there is some current even to the confines of the field. Indeed, it is thought that the greatest power of the current is not in the wire at all, but in a thin skin of ether around it, and that the wire is only a directing conduit through the obstructive, entangled air—a kind of blazed route, as it were.

It must be understood that this whole fabric of vortex rings, atomic rotation, ether waves—even the ether itself is inferential: that the mathematical analysis of motions in a perfect liquid lead to results that have their counterpart in the observed phenomena of electrical and magnetical experiments and investigations; and that, granted the existence of the ether, and that it is incompressible, devoid of viscosity, and made up of particles of infinite minuteness in closest proximity—in a word, that it is a perfect liquid, then vortex motion in it would account for the effects called electric and magnetic.

Such comparison affords a mental picture of observed phenomena, as the old fluid theory of electricity did; but while the latter was little more than a means of supplying analogies, the former is a rational explanation that some day may be confirmed as the reality.

And yet, it is well to remember that this, too, may collapse—like the electromagnetic field itself when the current ceases.

Section Three: Laws of Magnetic Action.

178. Attraction and repulsion.—If two cylindrical magnets like lead pencils, be laid side by side in one way, they will cling together with such tenacity that some effort is required to separate them; while if one be turned end for end and again be brought to the other, they will now push each other away, and roll apart, and cannot be made to approach without some effort.

They attract and repel, and as either action depends on which ends are brought near each other, it is evident that both ends of the same magnet differ in some respect: those that attract are said to be *un*like—those that repel, *like.*

And although the magnets be flat bars whose form prevents actual motion, this reciprocal effort toward such motion is none the less exerted; and it exists between magnets of every kind, size, and form—it is the moment, the torque, of one magnet upon another.

If the two magnets differ greatly in strength and temper, the more powerful may dominate the weaker—reverse its poles—and thus always show attraction between them.

Between magnets of equal strength and temper, the force of attraction is greater than that of repulsion; because in the former the opposite conditions intensify each other, whereas in the latter, like poles only exert a benumbing effect.

That the different actions of the two poles of a magnet do not necessarily imply any radical difference in their nature, but may be some peculiarity of condition, is shown by a vortex ring, where the particles of air and smoke in their rotary orbit rush in on one side and out on the other, giving to each side accordingly its attractive and repellant feature; or by a circular wire alive with current, which exhibits north polarity

on one side and south on the other—the exact analogue of a vortex ring.

179. Induction.—A magnet will excite a condition similar to its own in any mass of iron or steel brought within its influence—make of it a magnet also, the near end becoming unlike, and the remote end like, the corresponding poles of the magnet.

The process is said to be by *induction* when the surfaces are not in contact, though in reality there is no difference in kind between the magnetization by the weak field near its boundary and that by actual contact of magnet and iron; the degree, of course, depends upon the intensity of the inducing field, but it is the *field* in all cases that produces the effect: this fades as the iron recedes from the magnet and finally vanishes on passing out of the field. On the other hand, while under the spell, the iron strengthens the magnet, and, in fact, there is a mutual intensifying action, which, however, soon reaches a limit. It is the Earth's field that makes a more or less permanent magnet of every iron or steel ship, as well as of every other mass of either metal on its surface.

The character of the material determines both the amount and retentiveness of the induced condition: a tube of pure wrought iron which has been heated to redness and allowed to cool slowly, will be invested with a degree of magnetism scarcely less than the intensity of the inducing field, but it is as evanescent as a shadow; however rapidly the tube be reversed while held in a vertical position, the peculiarity of pole will flit from end to end with each reversal, and the lower will always be of opposite kind to the Earth's field, the upper of the same kind; a hard steel bar, on the contrary, is but little impressed by a mild field, but that little it retains; and between these extremes there are all degrees of iron and steel with varying receptivity or permeability.

The inducing effect is in no wise hindered by the interposition of non-magnetic substances: through wood, paper,

ivory, copper, glass, and lead; across water, flame, or vacuum—the magnet will exert its influence: but iron stops it, and within a shell or other bounding wall of this material, a compass-needle would experience little more directive force from the Earth or an exterior steel magnet than a rod of brass would.

The effect of interposition is only to remove the iron or steel into a less intense part of the field, where the latter, as in the case of a bar-magnet, varies rapidly for short distances.

180. Magnetic force varies inversely as the square of the distance.—The law of inverse squares is general throughout nature: it expresses the rate of variation of many phenomena—the gravitation of matter, the warmth of heat, the brightness of light, the power of electricity, the intensity of magnetism.

A familiar illustration of force is a push or a pull, and magnetic force exerts precisely this effort, as when two small tubular magnets, laid side by side, will roll apart or draw together according to the ends in juxtaposition.

The varying strength of the field around a magnet may be likened to the force of a mountain stream—great near the source; moderate with less grade and wider bed; and weak when spread out into a thin sheet over level ground: the rate at which magnetic intensity varies with the distance from its focus will now be treated.

Whatever uncertainty exists about the nature of magnetism, there is none about the push or pull it exerts between bodies endowed with it. Consider, then, two bodies that will do this. Such are two vortex rings, Fig. 279, but they are unmanageable; such also are two currents of electricity in circular conduits, which may be manipulated at will, and are the exact analogue of vortex rings: both ring and circuit act like magnets—exert a push or a pull according to the sides facing each other. In the ring, we can see the particles of smoke rush inward on one side and outward on the other, so

on one side and south on the other—the exact anal
a vortex ring.

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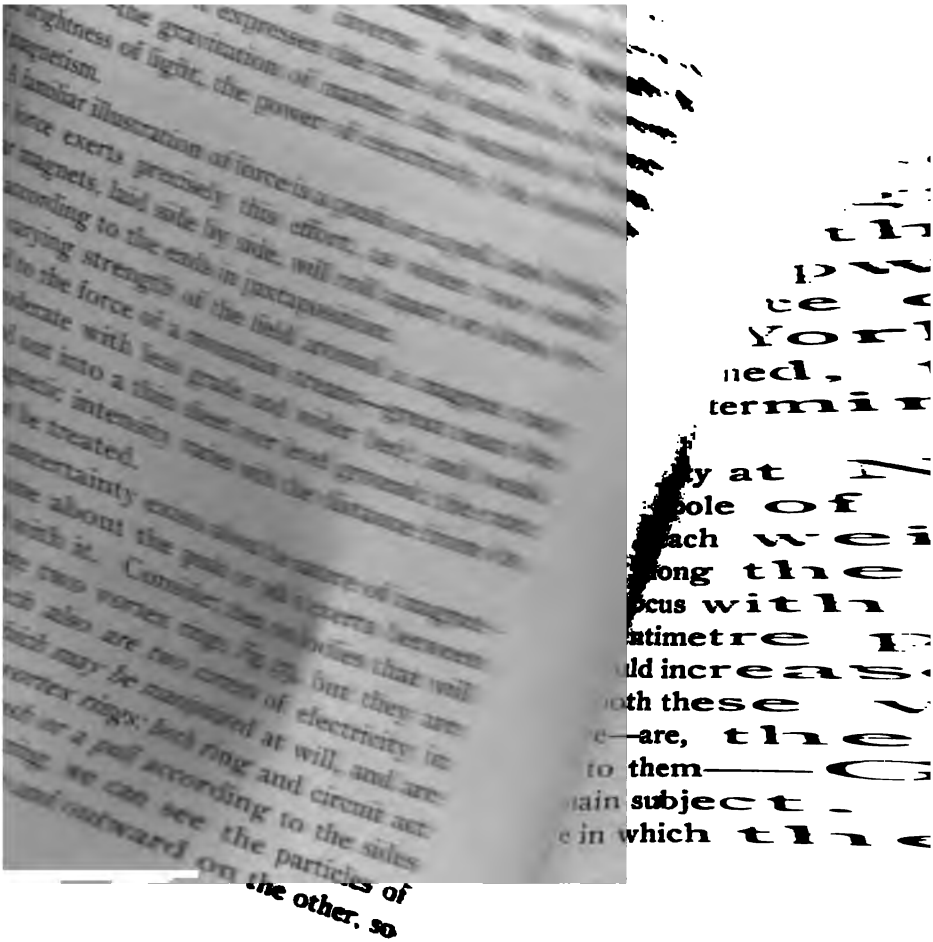

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that the difference in behavior of the two sides must be due to difference of movement merely—two aspects of the same thing: in the electric circuit, we cannot see any particles move, but that there is a difference between its two sides—two aspects of the same thing—is undoubted; one face will attract the north pole of a magnet and repel its south pole, and the other face will do the converse of this.

Vortex rings can be visibly formed in a material fluid—air and smoke mixed—and, as already stated, the mathematical results obtained from analysis of vortex motion in a perfect fluid have exact analogies in the electromagnetic theory.

Before proceeding further with the main subject, it is necessary to define the unit of measure of magnetic intensity—the *dyne*.

It is proved mathematically that the force of attraction of the Earth—gravity—acts upon matter on its surface as if the bulk of the Earth were concentrated at its center; as the equatorial radius is greater than the polar, this difference in the distance of objects on the surface from the center of attraction causes a slight difference in the force of gravity from equator to pole.

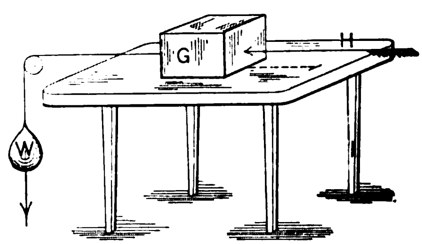


FIG. 284.

The weight of a body is the product of its mass by the force of gravity: the mass is everywhere a constant but hazy factor, while gravity varies slightly from place to place, but is always accurately known. This being understood, the weight of a body will be spoken of as representing it.

A gramme is the weight of a cubic centimetre of distilled water at 4° C. Let *G*, in Fig. 284, represent a cube of one gramme of copper: a human force *H* may *push* it, or a weight *W*—that is, in reality, the force of gravity acting on the mass of *W*—may *pull* it, and either force may be of degree to produce slow or rapid motion.

Let the force be exactly such that, acting on the cube *G* of one gramme, it will move it uniformly over a distance of one centimetre in one second: then this force has the value of one dyne. The cube *G* is supposed to move without friction on the table.

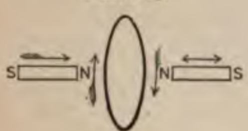
If the motion is not uniform, but steadily increasing, the *rate* of increase per second is a measure of the force: under the force of gravity a falling body steadily increases its velocity; at New York, *in vacuo*, the *rate* of this increase is 980 centimetres per second, or, the value of the force of gravity at New York, per gramme of matter, is 980 dynes—that is, to keep one gramme in mid-air would require an upward pull or push by a force of the value of 980 dynes: hence one dyne is equal to $\frac{1}{980}$th of the force of gravity at New York, and as the force of gravity can be accurately determined, the exact value of the dyne becomes known—it is a determinate fraction of the force of gravity at any place.

The Earth's horizontal magnetic intensity at New York has the value of 0.189 dyne: hence, if one pole of a magnet could be separated from the other, and each weighed one gramme, such pole would be attracted along the magnetic meridian toward the Earth's magnetic focus with a velocity steadily increasing at the rate of 0.189 centimetre per second, just as a falling body of one gramme would increase its velocity by 980 centimetres in one second; both these velocities—980 centimetres and 0.189 centimetre—are, therefore, the measure of the forces that give rise to them—Gravity and Magnetism. Now to return to the main subject.

Fig. 285 represents a circular wire in which there is a cur-

rent as indicated: if a magnet be brought toward each face, north pole nearest the ring, attraction will occur between pole and face on the left, and repulsion on the right; if the current be reversed, the converse of this will take place, as shown in Fig. 286—thus proving the duality of condition on each side of the circle.

FIG. 285.



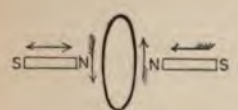
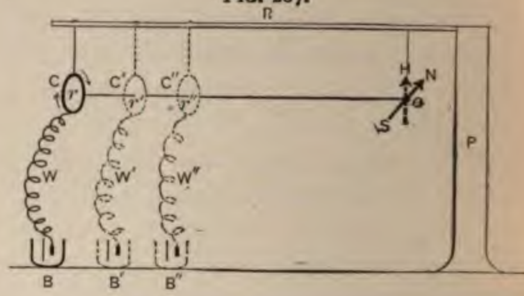


FIG. 286.

FIG. 287.



Two such circles will push each other away or draw together according to the sides facing each other, and the degree of either effort will be great or small with the varying strength of the current. In fact, a circle carrying a current, or any electric circuit, produces a magnetic field around it whose intensity is a measure of the current—a field whose exact equivalent may be produced by a steel magnet.

Consider in Fig. 287 that C is a ring one centimetre in diameter, supplied by current from the battery B at some distance, whose conducting wires are insulated and twisted together so as to neutralize each other's field and leave only that of the ring to act; this ring may be slid along a rod projecting from a pillar; at o is a small horizontal needle subject to deflection from the meridian by the field due to the ring C. Comparing the deflections at C, C', C'', etc., it is found that the force varies almost exactly as the inverse cubes of the distances ro, $r'o$, $r''o$, etc.: now this is precisely the law of variation found for a magnet in the broadside position, Fig.

271 and equation (28). Indeed if a magnet be provided of such moment as to balance exactly the needle *NS* against the field of the ring in one position, it will maintain the equilibrium in all corresponding movements of ring and magnet, thus proving their complete equivalence. The force of the field due alike to current and magnet is measured in dynes.

Now conceive two circles to shrink to molecular size and carry currents of such strength that the field of each exerts upon the other the force of one dyne at the distance of one centimetre: then these circles represent unit magnet poles, for they are equal to them; and of such unit-circuits a magnet of any size may be built up. Let one of the unit-circles be

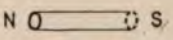


FIG. 288.

placed at each end of a glass filament one centimetre long, the north face of one and the south face of the other outward, as in Fig. 288, and this system represents a magnet of unit magnetic moment.

If two unit-circuits be placed near together in the same vertical plane with similar faces looking the same way, they will exert an effort twice as great as one circle would; three will exert three times the effort; and any number of circles, m, will exert m times the effort, which will be plus or minus according to the faces considered: similarly, any other multiple, m', of unit-circles will do the same, so that we have for the united effort of each group, $\pm m$ and $\pm m'$; now when these two groups are brought within each other's influence, every unit of the one will exert its effort on every unit of the other, which is equivalent to saying that the combined effort of both groups is equal to their product, $+mm'$ or $-mm'$, according to the side considered, the plus sign indicating that like faces are in juxtaposition and produce repulsion, while the minus sign indicates that unlike faces are so placed

and produce attraction. This agrees with the algebraic convention that like signs produce plus and unlike minus.

But the magnetic force between two bodies—whether they be congeries of unit electric circuits or of molecular steel magnets—is modified by the medium surrounding them. If this be air, it may be *considered* unity, for any alteration of its magnetic properties with ordinary pressure and temperature is imperceptible; but if it be anything else, the force will vary, and the variation is represented by μ; this is called the magnetic permeability of the medium, and depends on some unknown physical property; hence μ cannot be determined absolutely for any medium, but only its ratio for different mediums. If the bodies m and m' be immersed in a strong solution of iron, for instance, the force between them will be less than in air. If μ is large, the force is small, for the medium absorbs, as it were, the field of each body to some extent.

Regarding the law of inverse squares proved, as it will be presently, we can now express the value of the force F between two magnetic bodies of any size, in any medium, and at any distance, by the equation

$$F = \pm \frac{mm'}{\mu r^2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (49)$$

the upper sign denoting mutual repulsion and the lower mutual attraction. Their fields are inextricably mingled: if the bodies be moved closer together or further apart, this will change the intensity of their joint field. Two such mutually dependent quantities are said to vary directly when both increase or decrease together, but *inversely* when one *de*creases while the other *in*creases, and this is the case with magnetic intensity and distance.

Consider distances of 1, 2, and 3 inches from a focus of magnetism: if the intensity be unity at one inch and it varies inversely as the distance simply, it will have the value 1 at one inch, $\frac{1}{2}$ at two inches, and $\frac{1}{3}$ at three inches; if it varies inversely as the square of the distance, that is, $1^2 = 1$, $2^2 = 4$,

$3^2 = 9$, it will have the value 1 at one inch, $\frac{1}{4}$ at two inches, $\frac{1}{9}$ at three inches; if it varies inversely as the cube of the distance, that is, $1^3 = 1$, $2^3 = 8$, $3^3 = 27$, it will have the value 1 at one inch, $\frac{1}{8}$ at two inches, $\frac{1}{27}$ at three inches; and it is evident that it may vary according to any other power, either whole or fractional, of the distance: the experimental means of determining the exact ratio will now be described.

The law presupposes interaction between very small

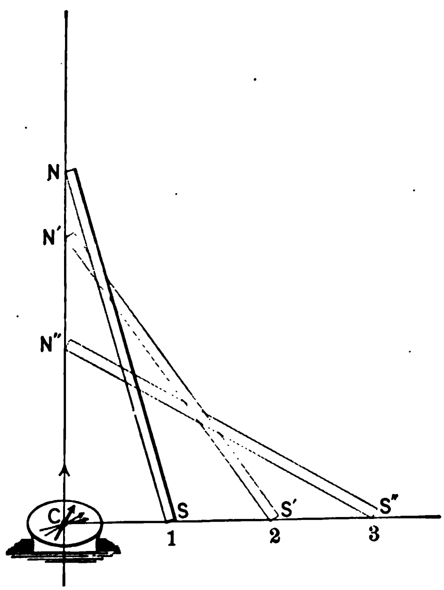


FIG. 289.

bodies—even points, and is not at all true for extended surfaces like the polar areas of large magnets: furthermore, the near poles of both magnets are alone considered, whereas the remote ones cannot be ignored, for they *do* modify the effect, lessening it.

There are four principal methods of determining the law of magnetic force: 1st, by oscillations of a small needle, for they will be fewer and fewer as the force is less; 2d, a variable

magnetic force may be balanced against the constant one of gravity at a place, by means of the bifilar suspension of a magnet; 3d, a small needle may be variously deflected by the receding pole of a long magnet; and 4th, magnetism may be balanced against torsion. Only the 3d and 4th will be described—the 3d briefly, as it is mostly illustrative, and the 4th fully, since upon it rests the principal proof of the law of inverse squares.

Fig. 289 represents the 3d method: a long slender magnet

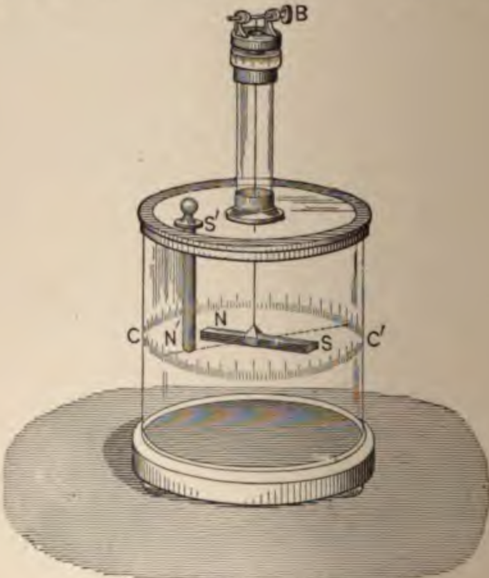


FIG. 290.

is placed so that its upper pole is always vertical above the center of the compass and therefore affects it but little, while the lower pole produces deflection, thus almost practically realizing the action of a single pole. The magnet is moved successively to positions 1—2—3, causing a diminishing deviation of the small needle *C*—an inverse variation of the force, since it *de*creases as the distance *in*creases: the tan[illegible] of these several angles of deviation, in this balance of

variable field of the pole S against the constant field of the Earth, are so many indices of the rate of change in the field of S as it recedes from the compass; and the rate is found to be inversely as the square of the distance.

The 4th method requires the use of the Torsion Balance, devised by Coulomb and employed in the following experiments by him to determine the law of magnetic force.

The instrument, Fig. 290, consists of a cylindrical glass vessel, surmounted by a glass tube; on top of this is a micrometer consisting of a cap fixed to the tube and a disc movable in azimuth; the former has a circle divided into 360° and the latter an index to point the angle of rotation; from the screw B is pendant a fine silver wire having a stirrup to hold a magnet NS, and through a hole in the cover another magnet $N'S'$ may be introduced; a graduated circle CC' is graven upon the vessel.

The force of torsion will be described in Part Sixth; but it may be said here, that if a cube of lead be hung from the lower end of a wire and the upper end be twisted, the torsion will extend down the wire and the cube will spin round; to prevent it, a force must be exerted in the opposite direction—say a weight hung from a thread passed over a pulley and attached to the end of a little lever through the cube of lead: the weight (which thus measures the force of torsion) will be proportional to the amount of twist, that is, the force of torsion bears a constant ratio to the angle through which the wire is turned, and hence this angle represents the force in amount.

Before beginning the experiments, the wire must be freed from twist by placing the magnet NS in the stirrup and turning the micrometer index and zero-line of CC' until both are in the direction of the magnet, that is, in the magnetic meridian; then the magnet is replaced by a similar bar of copper and this will eventually settle into the plane of no-twist; this plane must then be turned to coincide with the meridian.

Coulomb's experiments were made with two steel rods, each 650 millimetres long and 3 millimetres in diameter, both well magnetized, and alike in every particular.

By varied experiment, he found that the effective magnetism of these rods was practically limited to a distance of one-sixth their length from each end, and that even the center of effort of this—the resultant magnetic force of each half—its actual *pole*, was located only about twenty millimetres from the end of the rod.

The forces in action, in the experiments, are: the magnetism of the Earth; that of the steel rods; and the torsion of the wire—all evidently subject to variability, but which for the same time and place may be considered constant.

Now suppose the force of torsion to be strictly proportional to the angle of twist of the wire that gives rise to it, and that for any two instances, the force is denoted by f and f', the corresponding angles of twist being A and A'; then by the hypothesis just made,

$$f : f' = A : A'. \qquad (50)$$

Let B and B' be the deflections of a magnet caused by forces equal to f and f'; these forces may be represented by lines

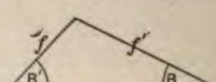


FIG. 291.

proportional to their amount, and then of these lines and of the angles B and B', a triangle may be formed, Fig. 291: hence by Trig.

$$f : f' = \sin B : \sin B'. \qquad (51)$$

or, by (50),

$$A : A' = \sin B : \sin B', \qquad (52)$$

whence

$$A' = \frac{A \sin B'}{\sin B}; \qquad (53)$$

or, taking the logarithms of both sides,

$$\log A' = \log A + \log \sin B' - \log \sin B. \quad . \quad (54)$$

By this equation, different values of A' may be computed for various deflections, B'; and then by comparison of these computed angles with those observed for the same deflection, it may be seen whether the *angle* of twist truly represents the *force* that produces the deflection.

The instrument having been prepared, one of the rod-magnets already described was placed in the stirrup, and being under the magnetic influence of the Earth alone, the following experiments were made:

TABLE 25.

(1) Number of Experiment.	(2) Suspension Wire Twisted by Turning Disc *B*, Fig. 290.	(3) Deflections of Magnet from Magnetic Meridian.	(4) Angles of Torsion of Wire = Difference of Columns (2) and (3).
Trial 1....	1 circle = 360°	10° 30′	349° 30′
" 2....	2 circles = 720	21 15	698 45
" 3....	3 circles = 1080	33 0	1047 0
" 4....	4 circles = 1440	46 0	1394 0
" 5....	5 circles = 1800	63 30	1736 30
" 6....	$5\frac{1}{2}$ circles = 1980	85 0	1895 0

$\frac{349.5}{10.5} = 33.3$
32.8
31.7
30.4
27.3
22.3

Taking trial No. 2 as standard of comparison and computing A' by means of eq. (54) for trial No. 3, we have the following data for that case: $A = 698\frac{3}{4}$, $\log = 2.8444$; $B = 21° \; 15'$ and its log sin $= 9.5592$; $B' = 33°$, log sin $= 9.7361$; whence A' is 1050°; observed value 1047°; difference 3°, or an error of $-\frac{1}{350}$. Computing in the same way the values of A' for trials 4, 5, 6, using the corresponding deflections of col. (3) for values of B', and the same values of A and B of trial No. 2 for all, the following results were obtained; and as they are based on the supposition that the *force* of torsion is proportional to the *angle* of twist of the wire, the closeness of the computed and observed values proves the truth of that hypothesis:

TABLE 26.

Trials 2 and 4 compared........	A' computed = 1387° A' observed = 1394	Difference 7°. Error + $\frac{1}{200}$.
Trials 2 and 5 compared........	A' computed = 1726° A' observed = 1736½	Difference 10½°. Error + $\frac{1}{165}$.
Trials 2 and 6 compared........	A' computed = 1921° A' observed = 1895	Difference 26° Error − $\frac{1}{72}$.

The next step was to determine experimentally the value of the Earth's magnetic effort in terms of the torsional effort, or in degrees of twist of the wire. The instrument was prepared anew—suspension wire freed from twist, zero-lines of circle and micrometer turned in the direction of the rod, magnet already described in the stirrup and at rest in the meridian, with only the Earth's magnetic couple to act on it: then the wire was twisted two circles, or 720°, by means of the disc *B*, Fig. 290, deflecting the magnet, which stopped at 20° from the meridian, thus making the actual angle of torsion 720° — 20° = 700°. In this balance of torsion against magnetism, one degree of deflection is equal to thirty-five degrees of twist, since 700 ÷ 20 = 35. Finally, the instrument was again prepared as above to determine the rate of change of magnetism with varying distance from its focus.

The magnet *N'S'*, Fig. 290, identical with the other, was now introduced vertically in the meridian of the suspended one and moved down until their poles, as previously determined, that is, twenty millimetres from the ends, were in juxtaposition: north poles being opposed, the suspended magnet was repelled, introducing twist into the wire until its force equalled the force of mutual repulsion between the poles, when the magnet stopped at 24° from the meridian: then, by means of the disc *B*, Fig. 290, more twist, three circles, or 1080°, was turned into the wire, thus forcing the suspended magnet back to within 17° of the meridian: finally, the disc was turned eight circles more, or 2880°, driving the magnet still closer, 12° from the meridian. In these three cases the forces in action were: on one hand, the mutual repulsion of the north poles of both magnets—on

the other, the directive magnetic force of the Earth and the force of torsion.

Since each degree of *deflection* produced by twist was found to have a *torsional* value of 35°—that is, the magnetic force of the Earth, as well as that between the magnets, has this value of 35° of torsion for every degree of deflection—we can now reckon in torsional effort the forces on both sides of the three cases just stated.

1st Case: 24° deflection equals $24 \times 35 = 840°$, the torsional value of the Earth's magnetic effort to bring the magnet back to the meridian; add to this the actual torsion due to the magnet itself lying outside the meridian at the angle of 24°, and we have 864° as the total torsional value of both forces on one side; on the other, is the repellant magnetic force of both north poles, of equal torsional value, since the forces on both sides balance. *2d Case:* 17° deflection equals $17 \times 35 = 595°$, the torsional value of the Earth's magnetic directive effort; add to this the 1080° of twist to force the magnet from 24° to within 17° of the meridian, and also 17° of twist due to the magnet lying by that amount outside the meridian, and we have a total of 1692° to represent both the directive force of the Earth and the torsion of the wire in their balance against the repellant magnetic force that kept the magnet 17° from the meridian. *3d Case:* 12° deflection equals $12 \times 35 = 420°$, the torsional value of the Earth's effort; add to it 2880° of twist to force the magnet from 17° to within 12° of the meridian, and also 12° for the twist of the deflection of that amount, and we have 3312° to represent the total torsional effort of Earth and wire in equilibrium with the repellant force of both magnets to keep one 12° from the meridian.

In these three cases, considering the *arcs* of deflection (24°; 17°; 12°) as the *distances* at which the repellant force of magnetism was measured and found in torsional value to be represented respectively by 864°, 1692°, 3312°, we should have

for the exact *inverse* squares of 24, 17, and 12, the numbers $\frac{1}{576}$, $\frac{1}{289}$, and $\frac{1}{144}$, or $\frac{1}{4}$, $\frac{1}{2}$, and 1, to which the preceding fractions are proportional; and the numbers 864, 1692, and 3312 bear to each other very nearly the proportion of the fractions $\frac{1}{4}$, $\frac{1}{2}$, 1, so that the magnetic force is thus experimentally proven to vary inversely as the square of the distance.

Besides errors of observation, the foregoing procedure has actual conditions differing from the ideal: in the first place, only the force between single isolated magnetic *points* should be determined, whereas the magnets used, were really very long knitting-needles, and although only sections three millimetres long (containing the poles) were in juxtaposition in the horizontal plane, still all the magnetic elements of the one needle *did* act upon all the elements of the other—at a great disadvantage and with small effort, to be sure, but yet enough to militate against the rigorous proof of the law; secondly, the arcs of the circle are taken for the distances, whereas the force acts along the chords of those arcs, and chords and arcs do not increase strictly in the same ratio; that is, the chord of 12° being 0.2090, the chord of 24° is not twice this, but 0.4158; and even it is not the whole force along the chord that should be used, but only its component at right angles to the suspended needle (see Fig. 292). As the distances along the arcs are thus too great, so is the force in its entirety along the chord, and hence these two errors partly compensate each other.

This matter has been described with unusual detail, because, as far as I know, Coulomb's experiments are the ones upon which the law of variation of *magnetic* force rests.

But it must be borne in mind that the law of inverse squares is true only at short range between two magnetic *elements*—either particles of a material substance, or molecular electric currents; when the action is between two *magnets* whose size is moderate compared with their distance apart, the force, as

already shown in Section Two of this chapter, varies inversely as the *cube* of the distance; when a magnet acts upon a mass of soft iron, the attraction is inversely as the *simple* distance while this is considerable; but when small, the attraction is *directly* proportional to the *square* of the strength of the magnet.

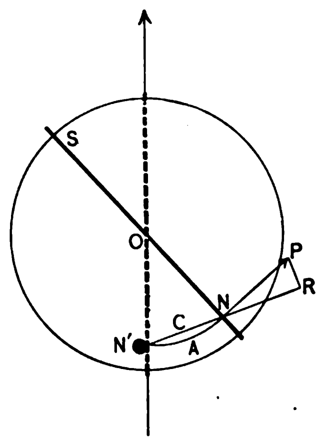


FIG. 292.

Coulomb also proved experimentally the law of inverse squares for electrical action, by using two small gilt pith balls at the ends of glass rods in the relative positions of the magnets just described: they were charged with the same kind and quantity of electricity and the procedure was the same as with the magnets.

By this means the law was then (about the year 1780) proved to the accuracy of $\frac{1}{60}$th part; but with the delicate electrometers of to-day, it has been proved accurate to $\frac{1}{72000}$th part.

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under similar circumstances will retain much of what it had acquired. If then a steel bar be heated to redness (by spirit-lamps) between the poles of a very powerful electromagnet and suddenly cooled with a shower of water in that position, this will make a more powerful magnet than when cold.

This same magnet, like soft iron, loses its magnetic condition completely at a white heat, and as iron in all its physical states is thus levelled by heat to the same inaction toward a magnetic needle that wood or glass is, it may be useful to explain this fact on the theory that a magnet is made up of atomic magnets or molecular electric currents. It will be recalled that the magnetic condition upon either of these hypotheses was the result of a magnetic flux through the particles—wheeling their axes into line: when a steel magnet is dissolved in nitric acid, no evidence of magnetism remains; it is like a multitude of very small magnets mixed up in a heap—their fields mutually neutralize each other and no resultant effect is discernible; yet each minute particle is still a magnet.

Now heat dispels the thraldom of the molecules of a magnet and their vibratory motions produce a helter-skelter mingling that prevents any resultant field; but when they cool while permeated by the magnetic flux, they return to uniformity of direction and we have the magnetic condition restored.

182. Strength of magnets changed by heat and cold.—The temperatures experienced by the Compass in either seasonal or geographical changes make it *slightly* stronger or weaker—more quick or slow to move, but does not affect the direction it points out: as heretofore shown, its position is one of equilibrium between two contending fields, that of the Earth and that of the Ship—it enters into each, and disappears in their balance.

Hence, what will be stated here has reference only to other magnetic instruments, whose indications in different temper-

atures must be reduced to one standard in order to be comparable; and only those ordinary changes of heat and cold experienced with time and place will be considered.

Generally speaking, all magnets lose power when heated and regain it when cooled, though very recently the contrary has been found true under special conditions; but every magnet has a temperament that determines its own rate of change. Let t_1 denote a standard temperature and t_n any other; m_1 and m_n the intensity of pole at t_1 and t_n; and a the peculiar nature of the magnet: then its change of strength is represented by

$$m_n = m_1[1 - a(t_n - t_1)]. \quad . \quad . \quad . \quad . \quad (55)$$

Relative values of a magnet's strength with reference to a standard may be determined by experiments of oscillation or deflection: only the latter will be described, as it is the more accurate and can be performed with the instrument used in a magnetic survey.

Fig. 293 represents the magnetometer arranged for the

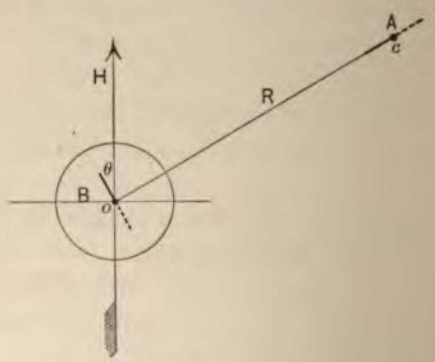

FIG. 293.

experiment: the magnet A is at first immersed in a freezing mixture contained in a vessel mounted on the bar R; heat is then applied to the mixture and the exact temperature noted by a thermometer; A is kept at a constant distance from B.

and turned at right angles to it in all deflections, these being read on the horizontal circle.

The forces in action are: on the one side, the field of the Earth and torsion of the suspension thread—both considered constant on account of the short time of the experiment and the small twist turned into the thread; on the other, the varying magnetic intensity of A, due to the different degrees of heat. As the torsion aids the Earth's effort and is proportional to the angle of deflection, it may be merged into the couple of the Earth. Expressed analytically, the moments in equilibrium, then, are:

$$(2m'l')(2ml)(R) = (2m'l')H \,.\, \sin\theta,$$

or,

$$(2ml)R = H \sin\theta, \quad \ldots\ldots\ldots \quad (56)$$

in which $(2m'l')$ is the magnetic moment of B and $(2ml)$ that of A; R, the distance between the centers of both magnets; H, the Earth's field; and m the pole intensity of A.

Differentiating (56) with respect to m and θ, which alone are variable, we have

$$2 \,.\, l \,.\, R \,.\, dm = H \,.\, \cos\theta \,.\, d\theta; \quad \ldots\ldots \quad (57)$$

dividing this by (56), it becomes,

$$\frac{dm}{m} = \cot\theta \,.\, d\theta. \quad \ldots\ldots \quad (58)$$

By observing the deflection, θ, at the lowest temperature, and its small changes, $d\theta$, thereafter at each increase of heat, we can then by (58) calculate $\frac{dm}{m}$ for a series of temperatures, and thence trace a curve for that particular magnet, using temperatures for abscissas and values of $\frac{dm}{m}$ for ordinates. If we note θ at the standard temperature, m is obtained in dynes from (56)—all the other quantities in that equation be-

ing known in C.G.S. units—and then the ratio $\frac{dm}{m}$ derived from any part of the curve, is clearly the *change* of intensity in terms of the intensity at the standard temperature.

Varied and oft-repeated experiments by divers skillful observers have established the following relations between heat and the magnetic condition: weak magnets lose strength more easily and to greater degree than powerful ones; the loss for all magnets is not strictly in a constant ratio, but in a slightly increasing one with the higher temperatures; magnets must be subjected for some little time to heat or cold in order to be affected to the full measure of their surroundings —the action is not instantaneous; in general, the alternate heating and cooling of a magnet has a permanent deleterious effect on its intensity; between 0° C. and + 38° C. the change in intensity is proportional to the heat—that is, a change of 1° produces a definite variation of intensity; of 2°, twice this; of 3°, three times, and so on; up to about 100° C. the magnet will recover the strength it had at a certain temperature when cooled again to that same degree, but beyond 100° there is a definite loss that never reappears; when carried to a white heat every magnet, as well as all iron, lose the magnetic quality and affects a compass-needle no more than copper does.

Of recent years, experiments on a certain kind of music-wire have disclosed the fact that there is an intimate relation, on the one hand, between the length and diameter of the wire, and, on the other hand, the manner in which it is affected by heat, when magnetized.

Calling the relation of diameter to length a "dimension" ratio, it was found that by suitably changing this, a certain one was found for a particular kind of wire in which heating or cooling had no effect whatever on the intensity of magnetization. This is an important fact—of great use in the manufacture of magnetic instruments.

CHAPTER XI.

THEORIES OF MAGNETISM—MOLECULAR AND TERRESTRIAL.

Section One: Similarity of Magnetic Action of Steel Bars, Electric Solenoids, and the Earth.

183. **Value of a theory in any science.**—It is the object of experiment to discover the facts that stud any region of nature—to chip away every encasing substance and lay bare the immutable kernel for contemplation by the mind: it is the province of theory to exercise the imagination and reason upon the relative bearing of these facts—to explain them—to weave about them a fabric whose design shows order, regularity, and sequence, rather than mere agglomeration—to make this mantle of such form and size that, without undue stretching and piecing, it will cover new facts as they arise, and that others, obviously related to their predecessors, will not rend it.

A theory, besides thus affording a rational mental view of grouped phenomena, has the further value of pointing out the way in which new discoveries lie, and even sometimes of predicting the very nature of the facts to be found.

Facts are the isolated ingredients of which a theory may be compounded; and although the theory may be crude in the first workman's hands, still others of more skill continually arise, until at last a genius gives it a touch, and we have a masterpiece, as in the grand triplet of electricity-magnetism-

luminosity—a combined wave-motion—growing out of the simple undulatory theory of light. It was a high and pleasurable effort for the long line of workers in this vein from its primal uncovering until the whole ledge was explored; and such it is, and ever will be, in the perfecting of any theory.

It is the aim of this section to show that by the similarity of their action to that of a solenoid, a steel bar and the Earth may have the same basic principle of magnetism—an electric current: of molecular size in the former and terrestrial girth in the latter.

184. Evolution of the solenoid from a single loop and a steel magnet from a disc, and identity of action of both. —If a thin steel disc be rubbed with a bar-magnet, it will become a magnet, too—each side acquiring polarity of one kind; and if suspended by a thread, as at *D*, Fig. 294, it will face north and south: it is an *element* of which many may be

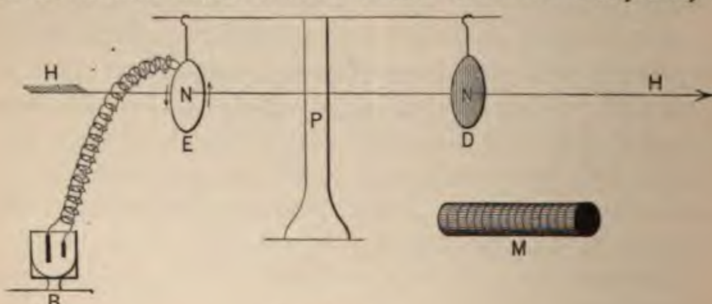

FIG. 294.

produced, and when several are united with sides of opposite polarity touching, they constitute the cylindrical magnet *M*.

If a loop of insulated wire be suspended by a thread, as at *E*, Fig. 294, and leading-wires extend to the battery *B*, the loop will face north and south when traversed by a current in the direction of the arrows: if the current be reversed, the loop will turn round until the face that was south, looks north; and a similar thing might be done with the disc by reversing its polarity with a bar-magnet.

The loop is an *element*, of which many may be formed, and thus arrive at the helix, Fig. 295—a solenoid.

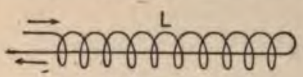

FIG. 295.

It is evident that the elements may be square, triangular, elliptical, or of any other shape, and the resulting magnet or solenoid will have corresponding form.

As the elementary disc and loop settled with their axes in the magnetic meridian, so will the magnet M and solenoid L when the former is hung by a thread from its center, and the latter free to move, as on a floating battery, Fig. 296; and the

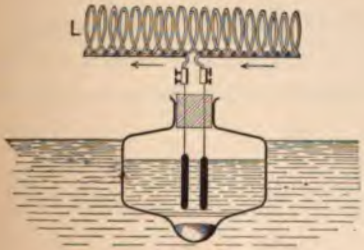

FIG. 296.

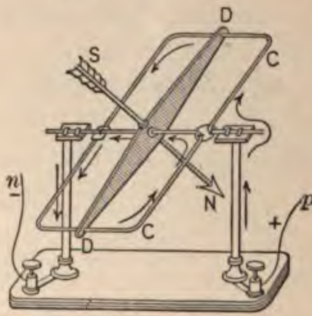

FIG. 297.

solenoid, whose virtue consists only in an electric current, is as truly a compass that obeys the direction and fluctuations of terrestrial magnetism as any steel needle. Even the Dip may be indicated by an electric current; consider Fig. 297: it consists of a frame C of copper wire, movable about a horizontal axis that rests upon metal pillars; D is a light wooden bar fixed in the frame, and NS an ivory arrow set at right angles to its plane; a current may enter the system at p, make the circuit indicated by the arrows, and depart at n; when this is the case, and the instrument has been set so that the arrow may revolve in the vertical plane of the magnetic meridian, the frame will turn until the arrow points in the line of Dip.

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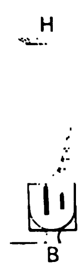

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current be a little distance from *F*, it will be drawn into parallelism with it, proving that *two currents in the same direction attract each other;* but if the branch *R* be near *F*, it will be thrust away, showing that *two currents in opposite directions repel each other.*

From these two principles flows a third—that *two currents, crossed* (in different planes) *without meeting, will move into parallelism.*

Consider Fig. 299: the sections *OC* and *OD* flow in the

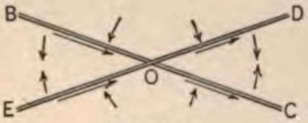

FIG. 299.

same direction and hence attract each other, and *EO* and *BO* do the same; but in *EO* the current flows toward *O*, while in *OC* it flows from it—two currents in opposite direction and hence repulsion, and the same is true of the branches *BO* and *OD* considered jointly: the combined result of these four efforts is to swing the wires into the same plane, and this is experimentally shown by a modification of Fig. 298; if a branch *ED* be added to *F*, and the floating wire *BC* be turned to make an angle with *ED*—crossed without meeting, as represented in Fig. 299 and above Fig. 298—then the moveable wire will turn until it is beneath *ED*, make a few oscillations, and then come to rest parallel to the fixed wire *ED*.

A sinuous current is equal to a straight one of like intensity. This is proven by Fig. 300, where the mobile insulated wire, pivoted at *C* and *O*, is straight from *M* to *N*, and then wound back in coils upon itself; when approached to the fixed wire *AB*, neither attraction nor repulsion will occur—*MN* will not move—proving that the spiral and straight currents completely neutralize each other. This principle is often used in leading-wires—twisting them together so that they shall not produce any effect: and upon this principle also—that be-

tween the same points a straight and sinuous current are equal—a bent wire may replace a straight one, or *vice versa;* or currents, like forces, may be compounded or resolved:

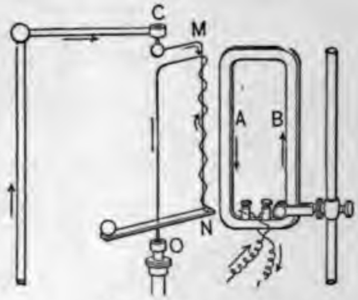

FIG. 300.

thus, in Fig. 301, we may have two branches *AB* and *BC* equal jointly to *AC*; or in Fig. 302 every element of a round

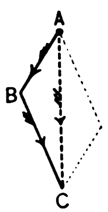

FIG. 301.

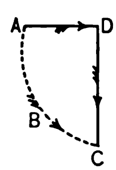

FIG. 302.

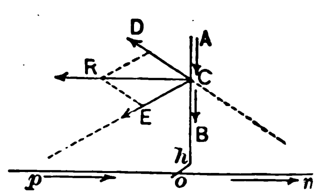

FIG. 303.

circuit *ABC* may be replaced by the rectangular components *AD* and *DC*. The import of this will be seen in the case of a round circuit being directed by an indefinite straight current.

The action of a current of indefinite length upon a short one—both straight and at right angles to each other—is illustrated by Fig. 303: let *pn* represent the indefinite current and *AB* the short one; this latter meets the horizontal plane at *h*, from which a perpendicular *ho* extends to *pn*; let the wire *AB* be free to move parallel to itself in the direction *pn*. The portion *po* runs *toward* the same point as *AB*, and the equal portion *on from* it, the one producing attraction represented

by CE, the other repulsion, denoted by CD, and both tending to move the wire AB bodily *toward* the left of the observer in the direction of their resultant CR, parallel and contrary to the current pn. If the current ran up in AB, its movement would be reversed: if the middle point C were at h, the actions on each half being equal and opposite, the wire would remain in repose: if unequal sections of AB were above and below pn, the difference of action on both would determine the amount of the moving force and its direction: if AB were fixed and pn free to move, it would do so—right or left according to the circumstances stated above. These various motions are deduced from the principles already established, but they can be experimentally shown by the instrument of Fig. 304. It consists of a circular trough filled with acidu-

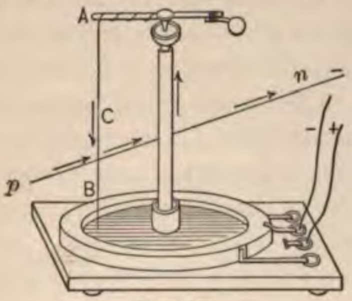

FIG. 304.

lated water, from the center of which rises an insulated metal column; a light wooden arm is pivoted and balanced on the top; a wire is wound about this—one end connecting with the column and the other dipping into the water; a current enters the column beneath the trough, traverses it and the vertical wire AB and departs by the water and another wire; the indefinitely long current passes through pn, and when this is brought near AB, it will cause the latter to move as described above under the different conditions.

The rotation of a short current by an indefinitely long one—both rectilinear—is illustrated by Fig. 305. The short cur-

rent flows from A to C and the long one from p to n; the wire AC is pivoted at C to admit of free rotary motion. By considering the relative directions of both currents in the successive positions of the short one, it will be seen that their mutual action is to cause the wire AC to rotate as indicated by

FIG. 305.

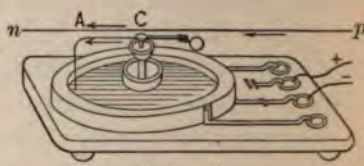

FIG. 306.

the arrow B: at A, for instance, AC and the portion Dn proceed *from* the same point D—hence attraction; while between AC and the portion ED there is repulsion, since one flows *from* the direction of the point D and the other *toward* it, both efforts moving the wire to A_1C, where the condition prevails of parallel and opposite currents and hence repulsion: this continues the movement to A_2C, and so onward—attraction and repulsion conspiring to rotation. If the short current were reversed, the movement of its wire would also be—a general feature of all these experiments; if pn cross AC between A and C there will be either equal effort on both parts of AC and hence equilibrium, or a difference of effort and hence motion one way or the other according to the conditions. All these movements may be demonstrated by the instrument represented in Fig. 306—so like in principle Fig. 304 that no description is needed.

The *directing* influence of a long straight current upon rectangular and round circuits is shown by Figs. 307 and 308: in the first the wire $ABCD$ is pivoted at E and F to attain free motion round the vertical axis XY; by turning it to make an angle pYB with the fixed wire pn, it is clear that the pair of

horizontal currents on each side of Y produce attraction; and by reference to the mutual action of vertical and horizontal currents set forth in Figs. 303 and 304, it will be seen that in Fig. 307 the currents in AB and pY, as well as those in Yn and CD, conspire with the pair converging to Y and the pair diverging from it to swing the plane of the rectangle parallel to pn. The same is true of the round circuit, Fig. 308, for

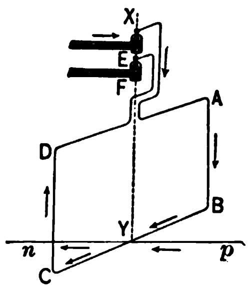

FIG. 307.

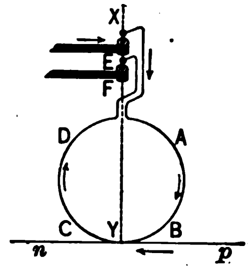

FIG. 308.

every element of it (as previously shown) can be replaced by horizontal and vertical components, and then the case reverts to that of Fig. 307. These two cases explain how the solenoidal current of Fig. 296 and the rectangular current, Fig. 297, indicate the Variation and Dip respectively, if we regard terrestrial magnetism as due to electrical currents circulating in the Earth.

The action of a circular current upon a short straight one

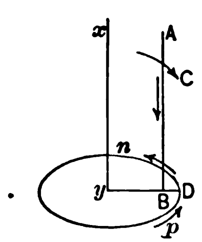

FIG. 309.

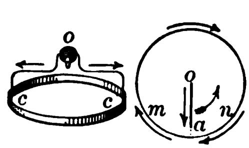

FIG. 310.

at right angles to its plane is illustrated by Fig. 309: at whatever part of the circular current the vertical one may be, there

is attraction on one hand, as at pD, and repulsion on the other, as at Dn, since these are cases of currents toward and from the same point; the result is that the wire AB will revolve about the vertical axis xy in a direction contrary to the circular current, as may be demonstrated by Fig. 304, after removing the wire pn from it, and sending a current round a metal band enclosing the exterior of the trough.

The mutual action of a circular current and a short straight one in a plane parallel to it is illustrated by Fig. 310, and may be experimentally shown by Fig. 306.

186. Mutual action of magnets and currents.—In this article some experiments will be described to show that a steel magnet may replace one of the currents in the foregoing actions of two currents on each other, and yet have the resulting phenomena identical in both cases: the warrantable inference is that the magnetism of the steel bar may be due to currents in its structure.

The directive force of a current upon a magnet is illustrated by Fig. 311. Without current in the wire, the needle will repose in the magnetic meridian, but with it passing from A to B, the needle ns being free to float on the water and turn on its pivot, will move up until its neutral zone is under

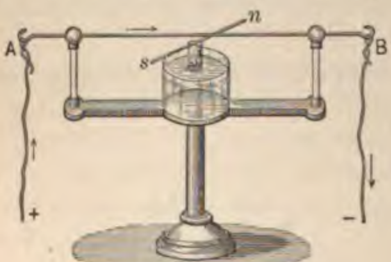

FIG. 311.

FIG. 312.

the wire and then turn across it: the degree of deflection will depend on the strength of the current.

If the magnet ns be conceived made up of small electric

circuits set at right angles to the axis of the magnet, its two ends will present the appearance of Fig. 312—currents moving like the hands of a clock (and this is the south pole), while others flow oppositely (and this is the north pole).

In reality, these are but two aspects of the same thing, as may be seen by drawing a circle on transparent paper and indicating the movement by arrows: looked at on one side, the motion is from right to left—on the other, from left to right.

Now on this hypothesis of molecular currents, consider Fig. 313—a quartering view of Fig. 312 (when straightened out) looking at the south end—and compare it with Fig. 308; in the latter, the mutual effort of circular and straight currents is to swing into parallelism in such manner that they

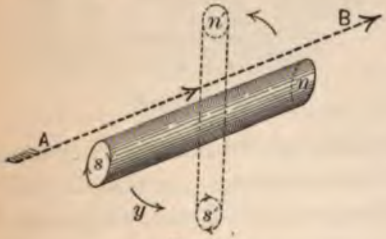

FIG. 313.

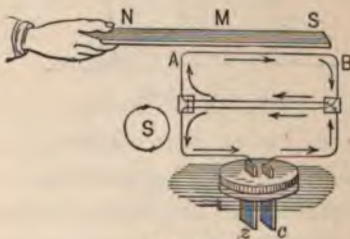

FIG. 314.

shall flow in the same direction, and this is accomplished in Fig. 313 by the magnet *ns* turning across the wire as indicated by the arrows *x* and *y* into the position *n's'*. The converse of the preceding—that a moveable current will take position across a fixed magnet—is also true: when the magnet *M* in Fig. 314 is brought down parallel to the floating wire, the latter will turn across the middle of the former with the *A*-end of the current to the observer's right as he looks from *N* toward *S*; should the magnet be thrust in between the horizontal branches of the wire and then drawn along by the hand, it will attract the floating battery with it; and if the poles of the magnet bear such relation to the rectangular wire that their hypothetical circular currents flow contrary to the

straight one, the floating battery will turn round until both systems have the same direction.

The rotation of a steel magnet by a current may be variously produced: only two instances will be described. In Fig. 315 a cylindrical magnet is pivoted vertically; if the cur-

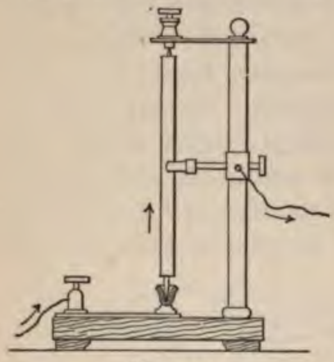

FIG. 315.

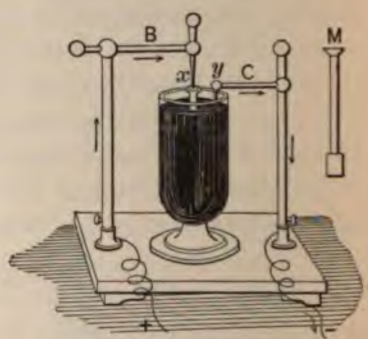

FIG. 316.

rent be led in at either pole and out at the middle by means of a metal spring pressing against its surface, the magnet will spin round its own axis; and conversely, if the magnet be whirled round its axis by any mechanical device, this will excite a current in the wire: indeed both facts have daily illustration—the latter in the dynamo, the former in the motor. But the current must not be led into one pole and out of the other, or at any two points equally distant from the neutral zone, for this would call equal and opposite forces into action and result in non-rotation.

The second instance of rotation is represented by Fig. 316: the magnet M, ballasted with platinum at the lower end, floats in mercury; its upper end forms a little cup into which the needle x dips while another needle y touches the surface of the mercury, thus closing the electric circuit indicated by arrows. From x the current spreads radially over the surface of the mercury as shown in Fig. 317—an instance of short straight currents acting on circular ones (those of the mag-

net), whose theory has been given in connection with Fig. 310—and hence rotation of the magnet on its axis is the result. If both the needles x and y dipped directly into the mer-

FIG. 317.

FIG. 318.

cury of the jar, the magnet would circulate bodily round the *axis* of the *jar*, and the reason is obvious.

The rotation of a current by a steel magnet is produced by the apparatus of Fig. 318: the wire *ABC* is pivoted at *B* and both ends dip into liquid in the annular vessel, thus affording a closed circuit for the current as indicated; upon pushing the north pole of a magnet up through the central hole of the vessel, the rectangular wire will turn around its supporting column as an axis; withdrawing this end, and entering the south pole will cause rotation in a contrary direction. A solenoid, in which circular currents are the active principle, will produce the same results—giving direct support to the hypothesis of molecular currents in the steel magnet.

Another illustration of the rotary effect of a steel magnet upon a current is afforded by Fig. 319: a fine silver wire carrying a strong current hangs loosely from a support sustaining a magnet, and when brought near this, the wire twines itself in spiral coils round each pole; if the magnet were flexible and the current passed through a rigid rod, the

former would encircle the latter—in fact the action is reciprocal, and is but the fulfillment of the effort made by a magnet and wire to turn across each other's axis as already illustrated in Figs. 311 and 314.

Liquids may be set in rotation by a magnet, as in Fig. 320: *A* is an annular vessel containing acidulated water upon which a cork ring floats with little flags to indicate the move-

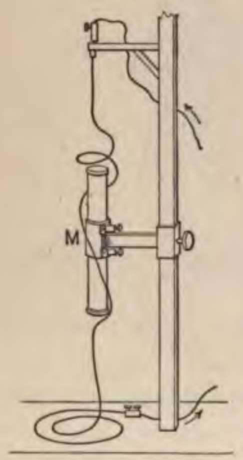

FIG. 319.

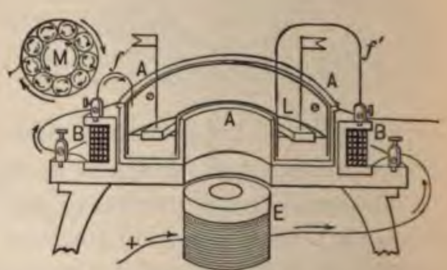

FIG. 320.

ment; strips of brass are attached to the walls of the vessel, and from them wires are led to a source of electricity—in, from *f* on the outer wall to the liquid, through this, and out at *f′* connecting with the inner wall. Both a steel magnet and a solenoid, when pushed up through the central aperture in the vessel, will produce identical effects—rotation of the liquid in the annular space—in strict conformity with the theory of the mutual action of currents.

If a stream of mercury flow from the upper pole of a magnet, it will be twisted in its descent to the lower pole like the strands of a rope—Fig. 321.

Gases, too, may be rotated by magnets, Fig. 322: a soft iron cylinder *C* rests on an electromagnet, by which it be-

comes magnetized; it is enclosed in a vessel partly exhausted of air; an electrical discharge through this is effected by connecting the terminals of an induction-coil to the vessel above one pole of the cylinder as at p and the other at its middle n. Under favorable conditions the glow of discharge down the

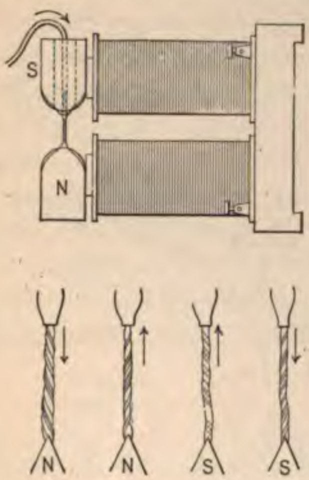

FIG. 321.

FIG. 322.

length of the vessel will be seen to revolve round the cylinder C. An experiment similar to this has already been described to illustrate the nature of the polar aurora—that it may be due to electrical discharges in the rarefied regions of the atmosphere: the aurora, like the experimental gas, has also a rotary motion round a magnet—the Earth.

187. Action of the earth upon electric currents.—Closed circuits and horizontal and vertical currents of short length are affected by the natural field of the Earth in precisely the same way that they are by steel magnets and currents.

The *directive* action of the Earth has already been illustrated in Figs. 296 and 297: it is more clearly shown in Fig. 323, where a circular wire pivoted in mercury cups at m and m' is free to move round a vertical axis; without current, it will rest in any position, but with it, as indicated by the arrows,

the wire will turn until its *plane* is perpendicular to the magnetic meridian, and in such manner that the current circulates in the lower half from east to west; if disturbed, it will return to this position, and if set so that the current in the lower half is from west to east, it will turn through 180° in order

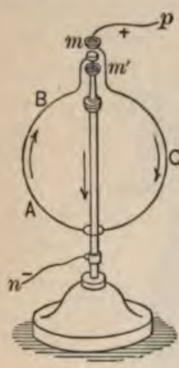

FIG. 323.

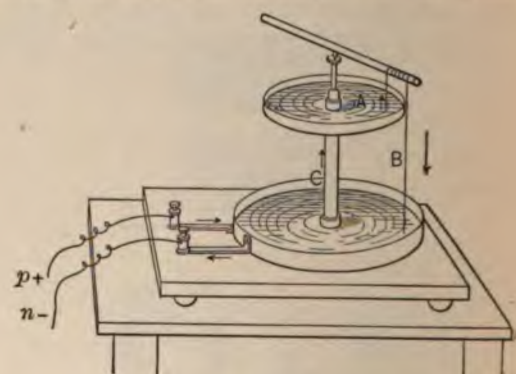

FIG. 324.

that the flow may be from east to west: from this, it is inferred that terrestrial currents also run from east to west, since this parallelism of both currents can only result from their flowing in the same direction.

Fig. 324 represents the means employed to show the Earth's action upon vertical currents: two shallow brass vessels supported on a metal column are filled with acidulated water; a light wooden rod is pivoted horizontally on the column; this is in contact with the fluid in the upper basin but insulated from that below; a light wire is coiled around one arm of the wooden rod with one end dipping into the water above, the other into that below; strips of brass beneath the lower basin establish communication with the battery; the current enters by the wire *p*, passes up the column, spreads radially over the water in the upper basin, into the wire *A*, around the coils on the rod, down by the pendant wire *B*, into the water below, and thence out by the slip *n* which is

connected with the water below. Considering the Earth traversed by currents from east to west, this is then the case of a short vertical current in the presence of an indefinitely long one—a case fully explained in connection with Figs. 303 and 304: there, it was shown that the vertical current being free to move, would do so—always settling in the vertical plane through its own wire and the horizontal one—and so it acts in Fig. 324; as the terrestrial current is predicated to run east and west, the vertical current *B* will set itself to the east of the column *C* if the flow in *B* be down, but to the west of *C* if it be up—in both cases in conformity to theory.

If a rod with two wires, Fig. 325, be pivoted on the column, the current in each branch tends to place itself to the east of the column—the efforts counterbalance—and no motion results.

FIG. 325.

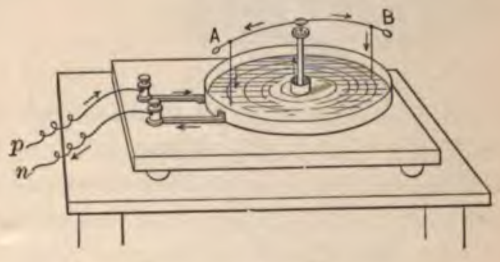

FIG. 326.

Fig. 326 illustrates the Earth's action on a horizontal current: it is similar to Fig. 324 and will be readily understood from the description of that; the current traverses the central column and departs by the horizontal and vertical branches of the pivoted conduit. As the flow is down in both vertical branches, their efforts neutralize each other, leaving only the horizontal current to be considered: it is the case of a short current in a plane parallel to an indefinitely long one—that of the Earth—a case described in connection with Fig. 305. The effort of the Earth is to give the horizontal branch *AB* in Fig. 326 a continued rotation whose direction depends on

whether the current flows out from the central column or in toward it.

188. Currents, solenoids, steel magnets, and the Earth—all induce currents in conductors.—If a long wire carrying a current be quickly approached to a metal ring, or suddenly withdrawn from it, either movement will induce a transitory current in the circuit. This fact is more forcibly illustrated by Fig. 327, where a solenoid *S* is thrust into a coil of wire *C* and quickly pulled out again: a reverse current with

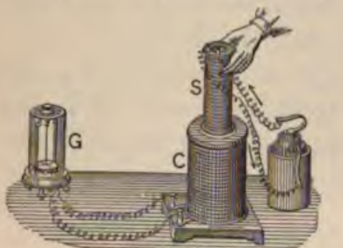

FIG. 327.

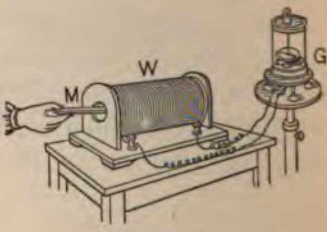

FIG. 328.

the former movement and a direct one with the latter will be indicated by the galvanometer *G*, and the intensity of both will depend upon the rapidity of motion of the solenoid. Results of precisely the same kind and degree are obtained by using a steel magnet in place of a solenoid—Fig. 328.

And without magnet, solenoid, single wire, or any other visible source of electricity, like effects are obtained from the natural field of the Earth. The means to this end are represented by Fig. 329: it consists of a wooden hoop *AB* grooved on the exterior to admit several turns of insulated copper wire whose ends finally lead out through a commutator at *p* and *n* to the galvanometer *G*; by means of a crank *H*, this hoop can be given motion round the axis *x*, set in the frame *CD*, and the latter has also motion round the horizontal axis *y*, the degree of each movement being indicated by pointers on circles at *E* and *F*. When set as shown in the figure, with the axis *y* at right angles to the magnetic meridian, and the

plane of the hoop perpendicular to the line of Dip T, the instrument is in position to have rotation of the hoop produce the maximum effect; when turned to have the axis x coincide with the line of Dip T, no result can be obtained: the reason is, in the former case the hoop cuts directly across the lines

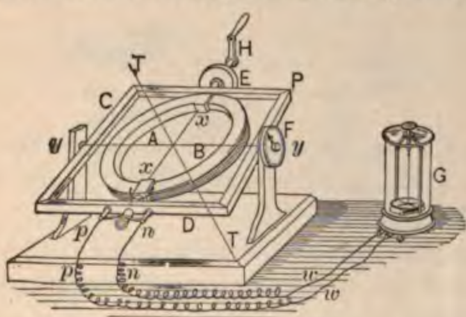

FIG. 329.

of terrestrial force, which action induces a current in the coil of wire, indicated by the galvanometer; when the axis x coincides with the line of Dip the plane of the hoop is parallel in all positions to the lines of force, and hence no result. In the first case, the current steadily grows from the position shown until the hoop has turned 90°, or is in the vertical plane of the magnetic meridian, then it gradually falls off to entire disappearance at half a circle rotation, or when the branches A and B have changed sides; the rotation continuing, the rise and fall of the current will be repeated, but in a contrary direction.

Still another instance will be cited of currents induced equally by a steel magnet, a solenoid, and the Earth. Let Fig. 330 represent a magnet suspended by a silk fiber inside a bell-jar exhausted of air; it reposes in the meridian; if drawn aside to an angle of 45° by the approach of another magnet, and then allowed to oscillate under the influence of the Earth's field alone, it will make a certain number of swings—say 400—before the amplitude is reduced to 10°; but if a

shallow copper vessel of little more diameter than the length of the magnet, Fig. 331, be placed on the glass plate of the bell-jar, so that the magnet shall swing inside it, and the for-

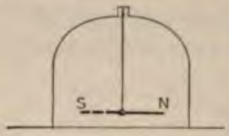

FIG. 330.

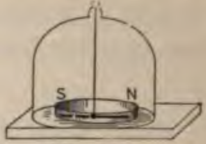

FIG. 331.

mer deflection of 45° be made, the number of oscillations will not be 400, nor even half that number, by the time the arc has been reduced to 10°.

As the magnet swings, the lines of force of its field are cut by the rim and bottom of the copper vessel, and hence electric currents are excited around the magnet—counter-currents to its movement which rapidly diminish its amplitude and bring it to rest. The intensity of the currents and hence their effectiveness to damp the magnet's motion is dependent on four things: the rapidity of oscillation; proximity of the magnet to the surrounding vessel; the material of which this is made; and the strength of the magnet itself. Considering the susceptibility of copper to currents as 100, the relative susceptibility of other substances are: zinc 95, tin 46, lead 25, antimony 9, bismuth 2, and glass 0: *therefore an oscillating needle for intensity experiments, where a large number of oscillations are desirable, should be wholly enclosed in a glass, and not in a metal, vessel of any kind, in order that its motion may be unimpeded by induced currents.* If the bell-jar and magnet be put on a whirling table, Fig. 332; the air exhausted as before, and a copper disc be pivoted under the glass slab on which the jar rests, with a means of giving the copper disc rotation as indicated, then when this is done, the magnet will at first be deflected, and eventually drawn round and round by the movement of the disc. The magnet moves in a vacuum shielded from disturbing causes save the reflex action of the

currents induced in the disc by its cutting the lines of force of the magnet's field.

The converse of the foregoing is also true: if, as in Fig. 333, a cube of copper be rapidly spinning under the force of a twisted string, it will immediately stop when the current is

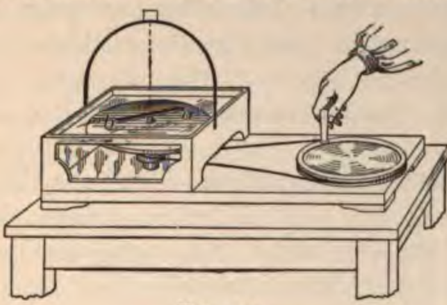

FIG. 332.

turned on the magnet; the strong field induces currents in the structure of the copper which arrest motion.

In the foregoing, a solenoid may replace the steel magnet with identical results.

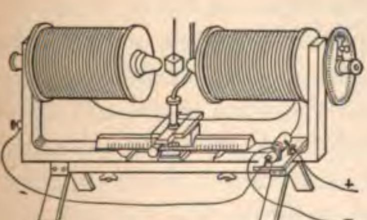

FIG. 333.

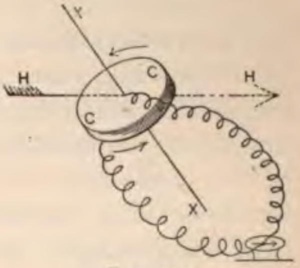

FIG. 334.

To produce them in the field of the Earth alone without either magnet or solenoid, a copper disc C, Fig. 334, is so arranged on a whirling table that its axis X is in the vertical *plane* through the magnetic meridan H; when the axis X coincides with the line of Dip, the plane of the disc in rotation round X cuts straight across the Earth's lines of force by which currents are excited in the disc; but if, while remaining

in the same vertical plane, the axis X be gradually turned out of the line of Dip, the induced currents will decrease, and finally cease when the disc is rotating *in* the line of Dip, for then its motion is parallel to the lines of force. The induced currents are indicated by a galvanometer from which one wire leads to the axis, and the other to the rim of the disc.

Since a current in a wire creates a field—a stress or whirl in the surrounding ether—all the foregoing effects of currents on each other are, in reality, the mutual action of their fields.

189. Terrestrial magnetism.—That the Earth is a magnet is irrefutable, but what kind of a magnet is it—like a steel bar, apparently composed of atomic magnets; or like a solenoid, pervaded by electric currents?

That there are masses of magnetic minerals spread with more or less density all over the globe, is undeniable; but that their greatest aggregations should be mainly in the polar regions, and that their minute particles should group themselves into symmetry of direction to make of the Earth a material magnet—this seems credible only as an act of creation. But such a hypothesis meets with facts not easily explicable by it: the daily, yearly, and secular fluctuations of terrestrial magnetism would require a corresponding undulatory motion of the crust of the Earth to produce them, and these should synchronize with the motions of the Earth about the Sun in order to account for the dependence of certain magnetic fluctuations on the relative position of Earth and Sun.

On the other hand, all the experimental facts adduced in this section—the mutual action of electric currents; the identity of action of one solenoid upon another with that of one steel magnet upon another steel magnet; and of magnet and solenoid on each other; and the Earth upon all—this identity of result, however varied the combination of current, solenoid, magnet, and Earth, points to the Earth as a solenoid with currents coursing round it in a general way from east to west.

And terrestrial currents do exist; they are phenomena of daily observation in different parts of the globe; moreover, the air is full of electricity: so that in and around the Earth there is that force that gives support to the solenoidal theory; and the fluctuation of a current to produce periodical variations in its accompanying magnetic field is a matter of far more easy acceptance than the heaving and swaying of a material magnetic shell.

The Sun undoubtedly has electromagnetic qualities, and its absence or presence with night or day, and its proximity or remoteness with season, would account for the fluctuations coincident with its apparent motions.

It is customary to say that currents result from *changes* in the Earth's magnetism, but this would still be true if that magnetism were due to a solenoidal condition, for a *change* in a current begets another current.

The current theory would account for the magnetic ores found everywhere, for the currents would magnetize them: in fact, this theory covers without rent or strain every phenomena of terrestrial magnetism.

But what is the origin of the currents themselves? The question has been answered variously; but—as with the origin of atmospheric electricity—by isolated suggestions, rather than by a comprehensive theory based on well-ascertained facts.

The principal of these suggestions are the following: *chemical source*—that the elements composing the Earth with the mineral waters percolating through them constitute a huge electric battery yielding unfailing currents; *thermal source*—that heat from within (the core) and from without (the Sun) acts on the metals and ores abounding in the Earth's crust, causing contact currents; *solar source*—that the Sun itself is in an electromagnetic condition which influences the portion of the Earth's surface upon which it shines; *gravity source*—that the crushing and grinding of the shell of the

Earth in its process of perpetual contraction, together with the violent actions of volcanic eruptions, create currents; *atmospheric source*—that the electricity of the air in motion is a modifying agent, causing fluctuations in existent currents as well as exciting others.

These are plausible explanations; and the sources stated do, no doubt, contribute to the currents found; but there is a lingering thought—a doubt, in the mind, as to their adequacy, either individually or collectively, to produce the full measure of the effects observed. The theory seems to point in the right direction, but the real sources of terrestrial magnetism have not yet been satisfactorily located, nor its true nature determined beyond question.

Section Two: Molecular Theory of Magnetism.

190. The characteristic features of a magnet exist in its smallest particles.—If a steel wire ten inches long be placed within a magnetizing coil, it will come out a magnet; if the tempering had been such as to render it brittle, it may be broken into ten parts, and each would be as distinctively a magnet as the original length; if every one of these be broken into ten parts, we obtain magnets one-tenth of an inch long, and however far the subdivision be carried—even to the fineness of pulverization—the characteristic features persist in the minutest part. By an oscillation experiment, Coulomb detected one part of iron in 132,799 parts of silver—the iron was chemically deposited on a slight scratch of varnish coating a silver wire, which then became a magnet to the extent of the iron on it.

If a glass tube be filled with the finest iron granules, it will not affect a delicately suspended magnet; but place the tube between the poles of a dynamo for a second, and then approach it to the needle, and it will be found a veritable mag-

net; shake the tube and its contents return to the neutral state, which, however, gives way again to the magnetic condition under the influence of a suitable field; and this alternation may be had as often as we please—neutrality by mechanical movement, magnetic condition through electrical force: from this it may be said that the latter merely confers a kind of grain or fibrous structure on the mass which the former upsets; but that the magnetic condition is innate in the granules themselves, which neither the mechanical effort destroys nor the electrical effort creates; and it further shows that the south pole is the inseparable companion of the north pole in every particle of magnetic matter, however small.

But this is all evidence of material particles that may be seen by the eye or perceived by the aid of magnifying glasses: there is still a subdivision of matter that exists only as a mental conception—the molecule and the atom. The eye of man hath not seen these, and yet there is evidence that in them, too, the magnetic condition resides intact and as distinctive as in the ten-inch steel wire.

If a gramme of pure distilled water be converted into steam, the fine particles are so many *molecules* of aqueous vapor; if these be further heated, they break up into *atoms* of oxygen and hydrogen; but no further subdivision can be made by any known process—we have arrived at (presumably) the elementary substance; and such also are carbon, iron, mercury, sulphur, and other elements forming the compounds of nature. If the oxygen and hydrogen derived from the gramme of water be weighed, they will not be found equal —the oxygen weighs 16 times more than the hydrogen. Now it is a law of matter in the gaseous state that equal volumes of the different elements under the same conditions of temperature and pressure contain the same number of ultimate particles or atoms; but these equal volumes will not be of equal weight: let that of hydrogen be denoted by unity; then, compared with that, it has been found that carbon is 12,

iron 56, tin 116, mercury 200, and so on; and these are the figures found in every work on chemistry opposite the names of the elements. In the gaseous state and under the like conditions in which each element is weighed, its mass is composed of the same number of ultimate particles or atoms—little bodies either differing in form, nature, and weight from element to element; or, different numbers and groupings (for each element) of a certain number of one primordial corpuscle, which difference then constitutes the different elements. In either view, the *relative* numbers given above are not only the weights of the volumes of the different gases, but since these volumes contain the same number of atoms, they are also the *relative* weights of their atoms—their specific gravity *relative* to hydrogen, *assumed* as unity; and furthermore, it is strictly according to these weights or multiples of them that the elements combine to form the myriad substances of nature. In the last analysis and contemplation of matter, it is these atoms and the molecules made up of them that must be considered.

When a sheet of lead, a bronze cymbal, or a golden plaque gives out its distinctive sound, what is it in each that vibrates? It is the ultimate atoms; and it is these in every substance that the forces of nature affect: it is these that torsion twists out of symmetrical arrangement; that heat separates; that electricity charges; that light illumines; that chemical action combines; and that magnetism attracts and repels.

To particularize some of these effects—the results of oft-repeated experiment: wires and carbon filaments carrying currents become brittle—a disintegration of their molecules. An iron wire increases in length when magnetized—a separation of its molecules; and there is even a relation between the elongation and strength of field, both increasing slowly up to a certain point, then the first more rapidly than the second, and finally a decrease of length with still greater

field. Water in a glass tube, made turbid by mixing powdered oxide of iron with it, will become clarified when placed in a strong magnetic field—the molecules are turned into alignment and light streams through their ranks. If a steel magnet be *heated*, *twisted*, or *struck*, its power will be lessened—showing that the forces acting on its molecules also affect its magnetic condition.

But it is in torsion that we find the most striking illustration: now, twisting a substance is so distinctly a derangement of its smallest particles, that, when produced by magnetic effort, it shows that it is upon these particles the effort is exerted. The following experiments are cited in support of the illustration. (Mr. F. J. Smith in the Phil. Mag., Vol. 32.)

A magnetizing coil, 50 cms. long, was prepared and connected with a source of electricity. Rods of iron, 50 cms. long and 0.16 cm. diameter, were well annealed by heating to bright redness and then cooling slowly: they were placed, one at a time, in the coil. In every case the rod hung vertically, fixed at the upper end, free to turn at the lower, and provided there with a mirror for reflecting a millimetre scale into a telescope.

The first rod had no initial twist: with current on and a field of 21 C.G.S.—units, the rod twisted, the lower end moving clockwise 0.1 cm. as one looked down its length; the current was stopped and the rod returned to its normal condition. The rod was then removed from the coil and a very delicate thermometer put into it; with the current turned on again, and the same field, there was no change of temperature from the first instance, showing that it was magnetic effort and not heat that produced the effect.

A second rod was fixed by one end, and the other end mechanically twisted eight times completely round; when released, it untwisted one turn, leaving a permanent set of seven circles in its fiber. As with the first rod, this was now

placed in the coil and the current turned on, giving a field of 21 C.G.S. units: instantly, the lower end turned five scale-divisions in the direction of its mechanical torsion. Next, the current was repeatedly turned on and off: with each "make" a twist of five scale-divisions resulted as before, and with each "break," a return therefrom. Next, the effect of a *gradually increasing field* was tried: this began at 19 C.G.S. units and produced a twist, *additional to the permanent mechanical torsion*, of 3 scale-divisions; with a field of 47 units, there were 6 scale-divisions of twist; with 86 units, 9 divisions; with 95 units, 10 divisions; and no further twist resulted, although the field was run up to 190 units.

The relation between *different* permanent *twists* of various rods and a *constant field* was next determined with results as follows: With one turn in a rod, it twisted in the constant field 3 scale-divisions more; with two turns in a rod, 5 scale-divisions; 3 turns, 6 divisions; 4 turns, 7 divisions; 5 turns, 8 divisions; 10 turns, 10 divisions; and this was the maximum. After magnetization, when the current stopped, the rods partly untwisted.

Nickel twisted similarly to iron and steel rods; but rods of non-magnetic metal—copper, platinum, lead, silver, zinc, cadmium, bronze, and bismuth—were all subjected to the same treatment as the iron rods, but no rotation of any kind could be seen.

In all the preceding, it was magnetic force that produced visible torsion of the rod: the converse is also true—that mechanical torsion of the rod gives rise to an electric current with its concomitant magnetic field. The following experiment establishes the fact. In Fig. 335, the iron rod *AB*, 50 cms. long and 0.4 cm. diameter, is held by one end in the vice *V*; it has a permanent torsion; *B* is a source of electricity, the wires *yy'* and rod forming the circuit for the current; *xx'* is a wire coiled round the rod, with a galvanometer at *G*. While the current was flowing, a mechanical couple *PQ* was

applied and turned 10° in the direction of the permanent twist of the rod: instantly, a deflection of 400 scale-divisions of the galvanometer showed that this torsion *changed* the magnetic condition of the rod (it being under the influence of the source *B*), so that a current was thereby induced in the

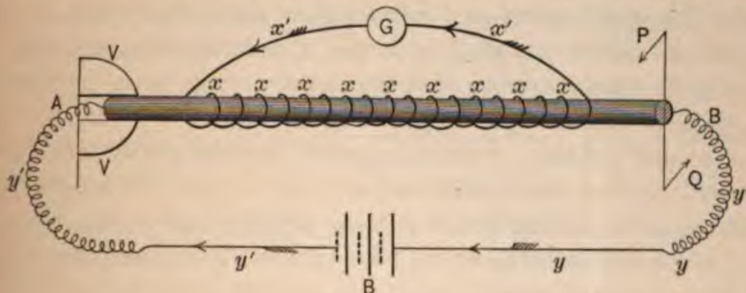

FIG. 335.

wire xx'; this transient current was reversed by reversing the direction of the couple *PQ*.

Long ago, experiment showed that an iron rod within a solenoid, through which an interrupted current passed, would give out a musical note—due to minute lengthening and shortening of the rod, which, however, was not under torsion.

In one of the preceding cases, when the current which traversed the long solenoid was interrupted by a tuning-fork driven electrically, an iron wire *subject to torsional set*, within the solenoid, gave out a loud musical note—due to torsional vibration, and that so great that when a light pointer was fixed to the free end of the twisted rod, a record of its vibrations was produced on the moving smoked glass surface of a chronograph: no difficulty was found in obtaining a clear-cut record of one thousand vibrations per second.

191. Magnets are composed of small magnetized particles.—This is a theory of remote origin which has come down with varying features as one physicist or another has left his impress upon it: quite recently it has received experi-

mental illustration from Prof. Ewing. What the nature of magnetism exactly is, forms no part of the theory: the fact is taken as a starting-point that every magnetic substance is composed of infinitely small particles, each ever and always a magnet in itself; that the indiscriminate mingling of these particles in any mass so confuses their fields that there is no resultant effect—no magnet—only a neutral state; whereas, when they are wheeled into line wholly or in part, we have a magnet of corresponding strength.

In any process of magnetization certain phases are observed in the metal under experiment: at first the magnetic condition is acquired slowly, then rapidly, and at last tends toward a limit which cannot be surpassed, however great the inducing power: shock, twist, and tension assist the process; and withdrawal of the inducing power leaves a residue of magnetism in the substance. To illustrate these phases and the theory of atomic magnets, a multitude of small magnets were prepared and variously grouped, and their behavior watched when under each other's influence alone, and also when controlled by a magnetic field.

Fig. 336 represents one of these magnets—a piece of steel

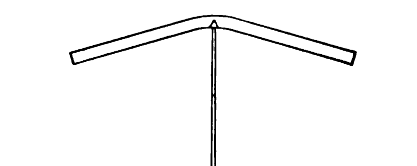

FIG. 336.

wire two inches long, one-tenth inch thick, bent at both ends to lower the center of gravity, and pivoted on a sewing-needle stuck into a little leaden base; the pole strength is sufficient to constitute the controlling force when two or more are near each other, thus masking the directive power

of the Earth; they swing freely in the horizontal plane—a representation but in part of the atomic magnets of a mass, which are free to move in any direction.

A large number of these magnets are set on a board in rows—by two's, in groups of three, of four, and more—their pedestals forming regular figures, but the magnets themselves assuming a variety of configurations: two alone set as in Fig. 337; a line of magnets generally forms as in Fig. 338,

FIG. 337.

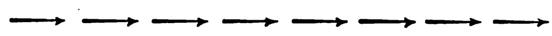

FIG. 338.

but again unaccountably becomes broken in sections, as Fig. 339; a group of four may take any one of the forms of Fig.

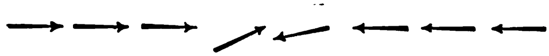

FIG. 339.

340 and a group of seven any one of the forms of Fig. 341; *and all this variety of voluntary configuration is held in partial*

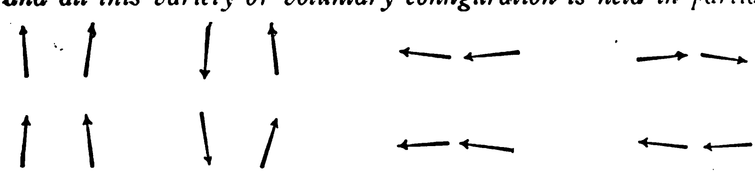

FIG. 340.

stability solely by the reciprocal pole influence of the magnets themselves composing any group. What a helter-skelter ming-

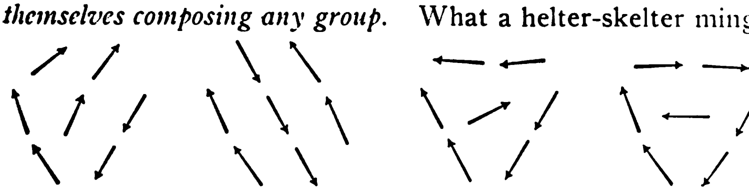

FIG. 341.

ling the atomic magnets of any *mass* of iron must form, since they are free to turn in any way! These various groupings produce no external magnetic effect, because they form

closed circuits, as it were, thus accounting naturally for the neutral state.

Now, with a multitude of these little magnets set in regular lines on a board, and the magnets themselves forming any configuration that their mutual polar influence impels them to, let a magnetic flux sweep through them, and observe the effect: this is best accomplished by sliding the board into an open rectangular frame wound loosely with wire, so that the magnets may be seen through the turns, and sending a current through the solenoid thus formed. At the first surge of the magnetic flood, a few of the little magnets swing into its direction and the assembled multitude begins to have an exterior field—the nascent magnet has had its birth; a stronger current, and more of the little magnets turn into line—the magnet grows and its field acquires expanse and strength; still stronger current, and eventually every one of the group forsakes the influence of its neighbor and becomes dominated by the inducing force; further

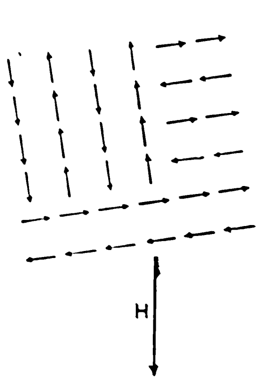

FIG. 342.

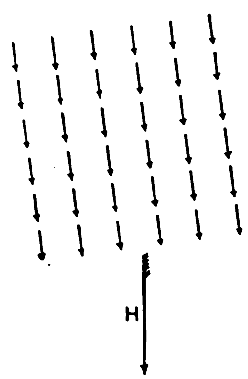

FIG. 343.

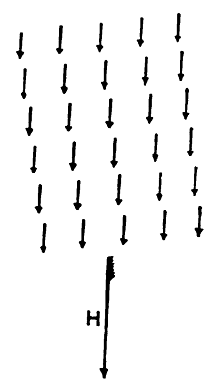

FIG. 344.

increase of this can do no more—the large magnet composed of small ones has attained its full power.

These several stages may be illustrated by Figs. 342, 343, and 344: in Fig. 342 we have the neutral state which gives

way, first slowly and then rapidly, to the magnetic condition of Fig. 343, where all the little magnets form columns, but still with a vestige of each other's polar influence keeping them out of line with the inducing power, H; this, however, finally controls, and the limit of possible magnetization is reached in Fig. 344, where every little magnet is parallel to the direction H of the inducing field.

From the avidity with which the south pole of one little magnet will seek the north pole of another, or from the varied configurations that a group of them will assume—*entirely oblivious of the weaker directing force of the Earth*—it is evident that this mutual magnetic affinity of the particles, when very strong, as it well may be in iron and steel, constitutes a sufficient force to account for the resistance of those

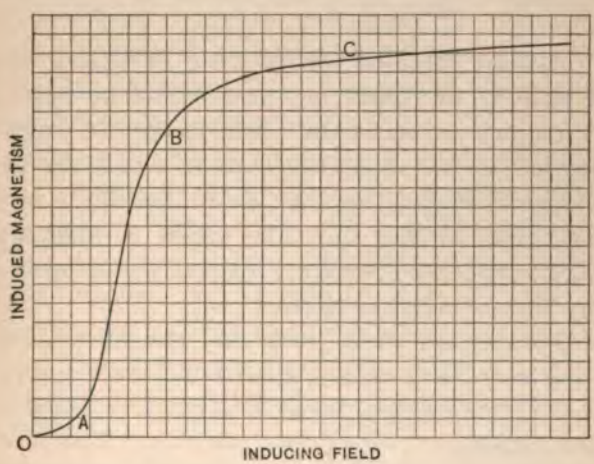

FIG. 345.

metals to *instantly* taking on the magnetic condition: as experienced in practice, it takes time to sever these natural bonds, and cause the agglomerate mass to exhibit one distinctive outward aspect.

The increase of the inducing field and gradual conformity

of the little magnets to its direction—that is, the corresponding growth of inducing and induced magnetism may be illustrated by Fig. 345: in this, values of the former are represented on the horizontal line, and of the latter on the vertical; the resulting curve grows uniformly from the origin *O* to the point *A*; then between *A* and *B* there is a large increase in the induced magnetism for a small increase of field; while from *B* onward the induced magnetism grows very slightly with large increase of field. The curve clearly tends toward a horizontal line—a limit of magnetization—saturation of the mass.

If at *A* the inducing field had been suppressed, the few small magnets that had swung into line and had created a weak exterior field, would return to their original position—the field would vanish—and there would be no residual magnetism.

On the other hand, if the inducing force had been suppressed only at the point *B*, there would be considerable residual magnetism: more than this, so set are many of the little magnets in the constrained position that the inducing field had put them, that they do not return to the same condition at corresponding opposite values of inducing field, but at all stages there is residual magnetism—a cycle of field produces what is called hysteresis.

Jarring the board upon which they are set, will evidently help to shake the little magnets free from their mutual thrall and give the inducing field better effect to turn more of them. and more readily.

And all this varied action of an inducing field upon a group of little magnets is what is experienced in the actual magnetization of a mass of iron by any process.

192. The magnetic condition due to electric currents.—Through the labors of eminent physicists it has been proved that many substances in nature are endowed with magnetism; and that iron, nickel, and cobalt are distinctively

so, only because they so far transcend other elements in this respect as to remove these completely from view. A parallel case is found in electrical conduction: there are few substances that give free transit to electricity, as there are also few that greatly obstruct it; it is only that some hinder so little, and others so much, that they have been classified as conductors and insulators.

In chemical processes, it is opposites that rush into each other's embrace, and we must conceive that it is their ultimate particles—the atoms—that thus combine: the action is akin to magnetic and electric attraction.

And again: when a solution of any kind—sulphur, salt, or nitre—crystallizes, it is its atoms that join end to end (like the iron filings in a magnetic field) to form the beautiful tracery characteristic of each substance.

Thus, duality of condition, somewhat like the poles of a magnet, is a feature that runs through all matter; and indeed its varied manifestations may be but so many phases of one—the electromagnetic condition.

In a previous part of this Treatise, it was shown that, for results produced and field around them, a thin steel disc magnet and a circular wire carrying a current are absolutely identical: let the disc and wire shrink to molecular size, and we have two views of the ultimate condition of magnetism—the magnetized particle and the electric current; both equally produce observed results. The magnetized particle has been represented as due to the separation of two fluids of opposite nature, whose recombination produces the neutral or non-magnetic state; but this is merely a material aid to a mental conception—the question still remains, what are the two fluids? and this question persists, however the idea of a magnetized atom be varied. But pursue the electric current to its last resort, and a plausible explanation is afforded.

In electrolysis, the liquid in the cell is broken up into

constituents, called *ions;* these may be single, double, triple, or otherwise multiple in their nature as regards their equivalence to certain other elements; but as regards the products of disruption of the electrolyte, they are always single—*ions*—entities of matter that seek the poles of the battery, one kind the anode, the other the cathode, and there deliver up the charge of electricity with which they are burdened, the one negative, the other positive.

Now every single *ion*, or monad, of whatever substance—hydrogen, silver, or chlorine—has a definite charge or quantity of electricity; every double *ion*, or *dyad*—as oxygen, zinc, or copper—has double that charge; every triple *ion*, or *triad*, has three times that charge; and so the quantity increases by successive multiples of the monad charge as we rise through the complex nature of the *ions* of different substances.

In view of what precedes regarding the universality of the oppositely dual condition of the particles of matter, it can hardly be thought that the charge is an adventitious result of some action in the cell—more likely it is an inherent attribute of matter itself in all its states—solid, liquid, and gaseous—and becomes manifest only in dissociation of the *ions;* and when it is said that these deliver up their charge, it may be that each *ion* only excites in the electrode a charge or pulse equal to its own. Consider, then, the charge a specific quantity on each atom, and let the atoms in all states of matter have a whirling motion on their axes, or an orbital movement, or both combined, like the Earth rotating upon its axis while revolving round the Sun, this combined motion differing, like the charge, from *ion* to *ion:* then this whirling-revolving-charged atom presents the essential features and effects of an electric current circulating round the boundary of the atom, and may explain the difference of magnetic condition in the myriad forms of matter; for instance, a heavy charge with rapid motion would explain the highly magnetic state of one,

while a light charge with slow movement the low magnetic condition of another.

These molecular circuits would behave in any grouping that may be made of them exactly like the little steel magnets previously described: if a congeries of them constitute a steel bar, its neutral state is due to the indiscriminate mixture of their axes, while the magnetic condition of more or less intensity results from a magnetic flux turning these axes in varying number parallel to the axis of the bar.

Consider the steel rod *M*, Fig. 346: it has been magnetized to the full, that is, all the little circuits have been wheeled into planes perpendicular to the axis of the rod; looked at from the south, the currents proceed like the hands of a watch—looked at from the north, they proceed in an opposite direction, as in Fig. 347, though both, in reality, are but different views of the same thing.

FIG. 349.

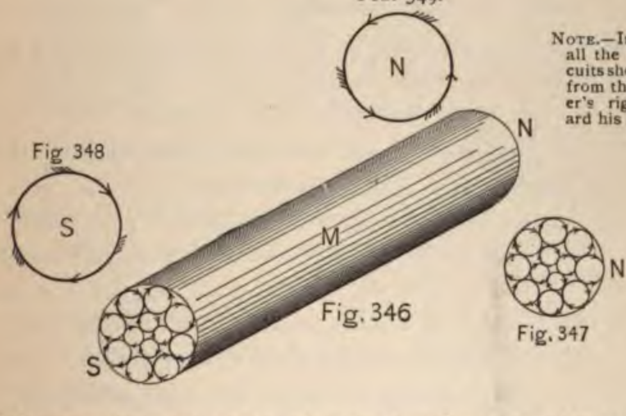

Fig. 346

Fig. 347

NOTE.—In Fig. 347 all the little circuits should flow from the observer's right toward his left.

Take contiguous parts of any two interior circuits, and it will be seen that they flow in opposite directions and therefore neutralize each other; it is only on the outer surface that no counteracting current exists, and here the portions present the aspect and effect of continuous currents flowing round the rod, as in Figs. 348 and 349, according to the point

of view; and the smaller the little circuits, the closer the approach to continuous currents on the outer surface; and when molecular, as in the hypothesis, the condition is closest to the semblance.

However much such a magnet be subdivided, it is evident that the smallest part—even the atom—will still present the features of a magnet.

Ampère's theory is, that the magnetic condition is due to currents of electricity circulating round the atoms of matter, and surely, it is more rational than the theory of magnetized particles; indeed it may be said to comprehend this, and besides, accounts for the ultimate condition of magnetism.

Section Three: Investigation of Terrestrial Magnetism by Means of its Potential.

193. **Value of this procedure.**—The analytical treatment of this subject aims to formulate its principles so that we can pass from what is immediately under view—backward, through what has occurred—forward, to what may happen, and be confident in both cases that we are treading the great highways of the phenomenon.

Thus, by computation upon given facts, we can fill in those desert places that (through want of observations) are devoid of reliable information regarding the magnetic elements. The theory presented in this section, and whose basic principles were first announced by Gauss, is of this nature: it establishes certain relations between the components of magnetic force which are true in general, and then expresses these components by formulæ whose solution depends upon observations. To test the accuracy of the formulæ, Gauss calculated the Variation, Dip, and Intensity for ninety-one places scattered over the globe from latitude 80° N. to 54° S. and in divers longitudes; upon comparison of the results with

the observed values, it was found that the agreement warranted the greatest confidence in the method: in the Variation, the differences seldom reached 1° in middle latitudes, while in high latitudes (where ships seldom go) they attained only as much as 5° in a very few cases.

Even these discrepancies can be greatly reduced by a more rigorous application of the method, so that it holds out the best hope of laying down with accuracy the lines of Variation, Dip, and Intensity that exhibit the magnetic condition of the Earth, without actually visiting its every region; and even if observations were made at a sufficiently large number of places to depict the magnetic curves from them alone, it is doubtful if the errors of all kinds entering into such observations would permit a much closer approach to the true state of terrestrial magnetism than would be afforded by Gauss' method of calculation, based on a smaller number of extremely accurate observations in highly favored localities.

194. The Potential.—The quality of magnetism upon which Gauss' theory is based, is its power to do work—its energy—its Potential—an attribute that runs equally through many natural phenomena, and to which the same mathematical treatment is applicable. It is like Pressure in Hydrostatics, Temperature in Heat, Attraction in Gravity, and Repulsion in Electricity: all these tend to motion—to do work.

Potential will be explained in an elementary way by means of electricity, as it affords the most striking illustration. Consider Fig. 350: A is an insulated metal ball charged with a quantity, e, of electricity; B is another, charged with *one unit* of the *same* kind of electricity; around each is a field —a stressed electrostatic atmosphere, dense near the balls but rarer and more thin as we recede from them, until eventually a limit of inappreciable effect is reached. Let T be such a point for both, B having been brought up from a great

distance; closer approach of B toward A, as at C and D, will bring both fields into conflict, with consequent repulsion, and this must be overcome by an effort—work must be done, the amount of which increases as the distance between the balls

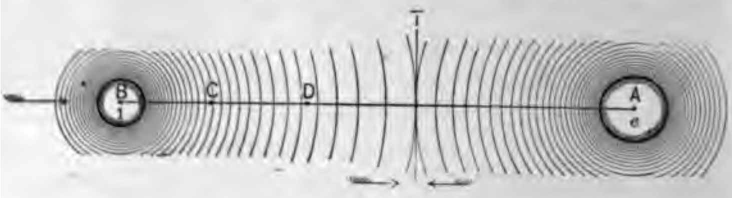

FIG. 350.

lessens: at every point, however, it is a definite quantity composed of two factors, the repulsive force, F, between the charges and the distance over which the movable ball B has been carried. Let $\mathbf{V}$ represent this work: it is also the power to do work—the Potential; for if the ball, when at D, be released from the hand, the work done and stored up as Potential becomes active and forces the ball back to the position B. If s is the distance from center to center of the balls, then the work, W, done in carrying B along any portion CD of the line, will be equal to the difference of Potential at the two points; that is,

$$W_C^D = \mathbf{V}_D - \mathbf{V}_C = F \,.\, \overline{CD}; \quad . \quad . \quad . \quad . \quad (1)$$

or, generally, considering differential quantities, $\mathbf{dV} = F \,.\, ds$,

or

$$\mathbf{V} = \int F \,.\, ds, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

the integration covering the length of the line.

Magnetic Potential is exactly like electric; and if one pole could be separated from its congener in any mass of steel, as a ball is charged with one kind of electricity, the preceding explanation would be directly applicable to Magnetic Potential: it becomes so at any rate by treating the other pole with

opposite sign, just as should have to be done with a charge of electricity of the other kind.

And magnetic work in no wise differs from electric—both, like the work done by a falling body, being expressed by the product of two factors, a force and the distance through which it acts, as in equation (2).

Around each ball in Fig. 350 is a series of circles drawn arbitrarily—they are sections by the plane of the paper of a nest of concentric shells: the surface of each shell being the same distance from the center, its potential has a uniform value, and the whole series is called equipotential surfaces; of course they may be few or many, according as we wish to stride through the potential or pass over it by imperceptible gradation. Lines perpendicular to these surfaces—in this case, radii from the centers of the balls—are called lines of force, and it is along such lines that electromagnetic bodies move when work is done: as work is equivalent to difference of Potential, therefore, no work is done when an electromagnetic body moves *on* an equipotential surface, and also it may pass by any route between two points of different potential and the work done will be the same in all cases.

Whatever Terrestrial Magnetism be due to—whether little magnetized particles or molecular currents—the field produced is the same: a region of force and potential, which, if visible like a hazy atmosphere, would appear dense in polar regions and thin in equatorial zones, and therefore of variable value from point to point both of the Earth and the space about it. This field, like the ring-growth of trees, may be laminated into equipotential surfaces—not the symmetrical shells of a uniformly charged ball, but warped surfaces, typical of the irregular distribution and intensity of terrestrial magnetism, and which hence have no necessary conformity to the surface of the Earth, but cut it irregularly: where this is the case, we have magnetic parallels encircling each pole in ever-widening contours until both systems meet in a line of

nul-potential—near the magnetic equator. Everywhere, perpendicular to these, are the magnetic meridians converging toward their respective poles. Fig. 351 illustrates the formation of magnetic parallels: the lower part is a vertical section through the Earth and its equipotential surfaces by

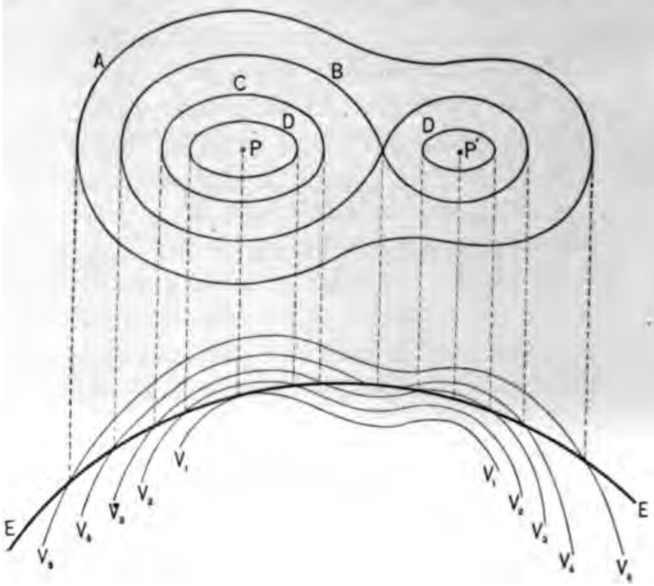

FIG. 351.

the plane of the paper—*EE* being an outline of the Earth, and $\mathbf{V}_1\mathbf{V}_2$ . . . $\mathbf{V}_n$ outlines of equipotential surfaces; above, at *ABCD*, are the closed curves *on* the *surface* of the Earth formed by the equipotential surfaces intersecting the surface of the Earth, just as the contour lines of rising ground result from a series of cutting planes at different levels. The figure represents two possible foci of *un*equal strength and same name, *P* and *P'*.

195. **The potential a function of coordinates.**—Since the intensity of the magnetic field varies from point to point, it is evident that this variability depends upon the *distance* of

whatever point is considered, from some origin. This distance may be represented in two ways—by a direct line, or by its components: consider a view of the northern hemisphere in Fig. 352; *M* and *N* are the magnetic and geographical

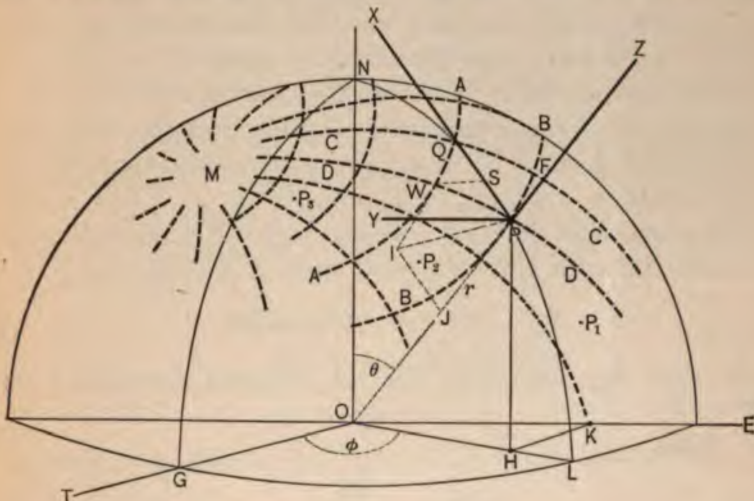

FIG. 352.

poles respectively; $\overline{OP}$, drawn in a definite direction, is the direct distance from *O* to *P*, but this point is equally well defined by drawing the rectangular components of $\overline{OP}$, that is, $\overline{OK}$, $\overline{KH}$, and $\overline{HP}$ parallel to the rectangular axes $\overline{OE}$, $\overline{OT}$, and $\overline{ON}$; or again, if *NGO* and *NLO* are great circles perpendicular to the plane of the terrestrial equator *OGL*, then *P* becomes definitely known by its latitude *LP*, and longitude *GL* from some prime meridian. Similarly, the points $P_1 P_2 \ldots P_n$ may be located, each involving a change in one or all of the coördinates to transfer it to a new spot either in the Earth, on its surface, or amidst outer space, where the Potential has a particular value—different from other places—and thus with every remove, even the smallest, the Potential, varying with the coördinates, becomes a function of them.

nul ... **the theory.**—In

per ... of the Earth's field

ing ... and the mag-

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se ... at the point P on

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... observer's zenith, and

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and in like manner the force F may be resolved in the direction of Y and Z; whence,

$$X = -\frac{\mathbf{dV}}{dx}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$Y = -\frac{\mathbf{dV}}{dy}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$Z = -\frac{\mathbf{dV}}{dz}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

In order to pass from rectangular coördinates to geographical latitude and longitude, let $NOP = \theta =$ co-latitude of P; $GOL = \phi =$ its longitude from Greenwich; and $r = OP$: then the equivalent differential expressions in both systems of coördinates are,

$$dx = -r \,.\, d\theta; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$dy = -r \,.\, \sin\theta \,.\, d\phi; \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$dz = dr. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Substituting these in (7), (8), and (9), they become:

$$X = -\frac{\mathbf{dV}}{dx} = -\frac{1}{r} \cdot \frac{\mathbf{dV}}{d\theta}; \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$$Y = -\frac{\mathbf{dV}}{dy} = -\frac{1}{r \,.\, \sin\theta} \cdot \frac{\mathbf{dV}}{d\phi}; \quad . \quad . \quad . \quad (14)$$

$$Z = -\frac{\mathbf{dV}}{dz} = -\frac{\mathbf{dV}}{dr}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

These three equations express the Magnetic Force at any point in, upon, or outside, the Earth, by three components: one, X, directed toward the geographical north; another, Y, toward the geographical west; and the third, Z, toward the zenith of the point—and all in terms of latitude, longitude, the radius of the spherical shell upon which the point is located, and the differential of the Potential at that point; this becomes restricted to the surface of the Earth by making r equal to its radius.

196. The fundamental equations ... Elements—
Fig. 352, consider a differential portion ... as follows:
bounded by the magnetic meridians ... PS by F. Dip
netic parallels A and B (this differen... compo-
greatly enlarged for the sake of clear... or its equal
a spherical shell of radius r, establ... surface of the
X, Y, Z—the last pointing toward ... an element
the first and second toward the geo... plane. let PS
respectively; X being tangent to ... from the
angle QPW formed by it and th...
the Variation—denote it by V, a
B are parallels of different poten... (16)
to both, the work done in passin...

(17)

$$V_B - V_A = F$$

(18)

the minus sign indicating th...
W to P.

From (3), (19)

$$F =$$ (20)

and thus the magnetic for...
differential of the potenti... (21)
differential of the norma...
same point. To resolve...
multiply it by the cosi... (22)

$$X =$$

but from the differe... (23)

(24)

whence substitut...

(25)

quations (18), (21), (23), and (25) give the Magnetic ments in terms of the components X, Y, Z; and these r, as seen by equations (13), (14), and (15), depend on latitude, longitude, and magnetic potential of the point nsidered. The complete solution of these equations as re- rds the Potential involves the employment of Laplace's unctions (or Spherical Harmonics, as they have latterly een called)—a branch of analysis of general application in ysical research, and which is beyond the plan of this Treat- e to deal with: suffice it to say, that it is a means of express- g in converging series, values of the quantities sought, and at the number of terms taken, determines the degree of curacy attained in the result.

CHAPTER XII.

THE ELECTROMAGNETIC THEORY OF LIGHT.

> "The electromagnetic theory of light adds to the old undulatory theory an enormous province of transcendent interest and importance; it demands of us not merely an explanation of all the phenomena of light and radiant heat by transverse vibrations of an elastic solid called ether, but also the inclusion of electric currents, of the permanent magnetism of steel and lodestone, of magnetic force, and of electrostatic force, in a comprehensive ethereal dynamics."
>
> LORD KELVIN.

Section One: Reciprocal Action of Light, Electricity, and Magnetism.

197. **Light excites a current of electricity, and produces the magnetic condition.**—Just as zinc and copper immersed in acid yield a current of electricity, so two sensitive plates may be prepared from a variety of substances which will produce a current in a wire connecting them when light falls on one of the plates while the other is screened: the light, like the acid, excites the flow and determines its direction—this alternating with the plate exposed. Combinations of such plates with a liquid are called photoelectric cells, in contradistinction to the ordinary voltaic cell.

Of all the metals, a seleno-aluminum cell gives the best

results: to form it, two clean plates of aluminum are prepared—*one* is spread with a thin layer of selenium, and both are then dipped in alcohol and connected by a fine wire, with a quadrant electrometer in circuit.

Upon exposure of the sensitive plate, it responds instantly to the luminous action by a movement of the electrometer-needle, and the current as quickly disappears upon withdrawal of the light. Even the passage of a cloud or interposition of the hand varies the current. A seleno-aluminum cell has been set in action by the light from a match a few feet distant, the current generated closing the circuit of a voltaic cell in connection with it and thus setting in motion the final object—an electric bell.

The cell transforms the energy it receives as *light* into an electric current, which in turn performs some useful work of a simple nature.

Although all light will excite electricity in a photoelectric cell, still the different colors produce currents of variable strength. When light is decomposed by a prism and the sensitive plate is successively exposed to the several colors, it is found that with some elements red excites but a feeble current, and blue a strong one, while with the seleno-aluminum cell, it is the yellow that creates the strongest current.

The element selenium illustrates in itself the influence of Light upon Electricity: experiments have proved that light falling upon a rod of this substance will start and maintain an electric current in it—the current rising instantly upon exposure to the light and ceasing upon its removal. Again: selenium in its ordinary vitreous condition is a very bad conductor of electricity, but when carefully annealed it acquires a crystalline structure that reduces the resistance; and as between light and shade its conductivity increases from 15 per cent in darkness to 100 per cent in daylight; even more, the conductivity increases as the light grows brighter: in some way the light opens freer passage to the electric current.

The following extract from Prof. A. E. Dolbear vouches for the fact that Light produces the Magnetic Condition: "Circularly polarized light is like water issuing from a garden-hose when the nozzle is swung round in a circle—it is a kind of spiral advance—and this was the nature of light reflected from the polished face of an electromagnet. . . . By the converse of this, that is, concentrating a large beam of ordinary plane polarized light with a quartz lens and passing it through a quarter-wave plate at the proper angle, a powerful beam of circularly polarized light was obtained. At the focus of this beam a fine cambric needle without magnetism was placed so that the light passed it longitudinally. Ten minutes' exposure was sufficient to make it decidedly magnetic.

"Hence I infer that the motions which we call magnetic attractions and repulsions may be quite analogous to such helical motions; also that these motions exist in ether, and evidently may be either right- or left-handed."

198. Spectrum lines resolved into two or more components by a magnetic field.—When a spark from an induction-coil passes between electrodes of any two elements—say cadmium and zinc—and its light is transmitted through a prism, the resulting spectrum is composed of a series of *bright* lines characteristic of the elements used. With no extraneous means taken to affect them, these lines appear to the eye as bands of definite width; but if the source of light be placed in the midst of a strong field created by a powerful electromagnet, the bright lines are no longer single, but multiple, and variously so.

A very strong field and high dispersive power of the prism are essential to produce these results.

Fig. 353 represents the decomposed lines of the spectrum: in (1) we have a band flanked by single lines of less width; in (2) a quartet—two central lines and two side bands; in (3) a doublet of bands; in (4) two pairs of same width; in

(5) a sextet of slender lines—and each group, the outcome of a bright line or band that was originally ***single*** and uniform. Furthermore, these resolved lines are polarized, and variously so; some circularly—others plane, and of these latter, in the case of a triplet, for instance, the polarization in the central line is at right angles to that in the side lines, as

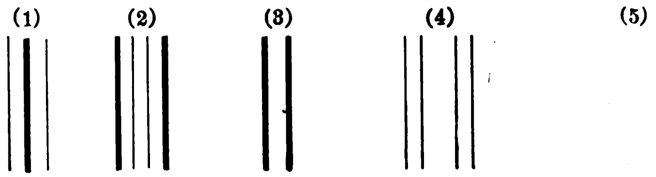

FIG. 353.

may be proven by a Nicol prism, which alternately extinguishes the inner or outer lines according to the way in which it is turned.

When the current in the electromagnet is stopped, these groups of component lines merge into their original single lines or bands of uniform aspect, only to appear again when the magnet is alive with current. It may be stated that what has thus been realized by experiment was at first partly indicated or predicted by the electromagnetic theory, which is based on the rotating-orbital motions of the electrons—the charged *ions* of matter.

199. Electric currents displaced by a magnetic field.—The action of magnetism upon electricity is proven by various facts: the electric arc, the brush-discharge, and the luminous bands of a vacuum-tube (which are only electrified streams of particles of matter) are all swayed and twisted about like flexible conductors, by means of a magnet AND A RAPIDLY REVOLVING DISC CHARGED WITH STATIC ELECTRICITY BEHAVES TOWARD A MAGNET LIKE A FEEBLE CIRCULAR CURRENT.

The following shows an intimate connection between electricity and magnetism: in Fig. 354, F is a sheet of gold

leaf to which the poles A and K of a battery B are led by wires; G is a galvanometer connected by wire to the equatorial line of the gold leaf, and matters may be so arranged that when the current passes, no deflection of the needle will occur; in this case, it is evident that the electricity spreads out in a uni-

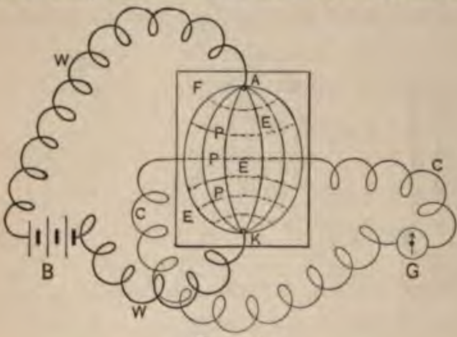

FIG. 354.

FIG. 355.

form sheet between the poles A and K, which condition may be represented by the symmetrical (solid) lines E . . . E; these are crossed at right angles by the equipotential (dotted) lines P . . . P, also symmetrical.

Now if this uniform flow be subjected to an intense field by bringing a pole of an electromagnet on *each side of the gold leaf F and perpendicular to its plane*, then the galvanometer-needle will be steadily deflected, its connections with the leaf remaining unchanged. The current through the galvanometer is due to a difference of potential, which can arise only by the electric flow in the gold leaf being *twisted* out of symmetry (as in Fig. 355) by the magnetic field, thus bringing points of different potential to the galvanometer terminals.

This effect upon the electric flow varies in both direction and degree with the kind of metal of which the leaf is made —it is feeble in gold, strong in bismuth, but in the same direction in both; while it is in the opposite direction in iron and tellurium, moderate in the former and immensely strong in the latter.

200. The plane of polarized light rotated by a magnetic field.—The ether of space may be a medium of close structure, like jelly or elastic rubber, in which case a movement in it would be of the nature of compression at certain points and dilatation at contiguous ones—a stress in both cases that is passed on as a deformation of the mass. It may also be of loose structure, like air, and then a movement would consist of an oscillatory, rotary, or right-line motion of the particles, or a combination of these motions.

The movement in the ether called Light is conceived to be a to-and-fro motion of the medium, either as a mass or as particles, *across* the path in which the ray is traveling.

By both natural and artificial means this movement is variously modified—polarized; that is, certain features have been observed in light to which this term is applied.

Polarized light may be plane, circular, or elliptical, though in reality the two first are but particular cases of the last: the three conditions will be illustrated in a crude way by mechanical movements, rather than an attempt made to explain them.

If a garden-hose be held steady in the hand, the issuing stream will have the semblance of a glass rod nearly straight: if the nozzle be moved rapidly from side to side, the stream will consist of undulations in a horizontal plane; if up and down, they will be in a vertical plane; both are typical of plane polarized light—a wavy motion restricted to one plane. If the nozzle be swung round in a circle, the stream advances in a symmetrical spiral; and if in an ellipse, the water describes a helicoidal curve: the former typifies circularly polarized light, and the latter elliptical. In this illustration, it is not asserted that the medium actually moves as the water does: it is only *motion* that is transmitted, as may be exactly illustrated by a rope attached at one end to a swivel in a wall, the other end being held in the hand; by moving the latter right and left, or up and down, or in a circle, or ellipse, the

corresponding sinuosities are identical with those of the stream from the hose; there is this difference, however—here, only *motion* is communicated from point to point; there, the *material particles* proceed onward.

Again, to afford another idea of the movement of light and its polarized phases, consider a wheel susceptible of motion along an axle at the same time that it rotates: let each spoke be the path of a molecule oscillating from hub to tire; then if the wheel be pushed (without revolving) along the axle, the direction of this axle is the ray, and the oscillation of the molecules along the spokes produces the movement called light. If all the spokes but two—those in the vertical line—be removed, we have oscillation—polarization—in the vertical plane only; similarly, if all but the two horizontal spokes be removed, we have polarization in that plane only; and it is evident that by suppressing all the spokes except any two in the same diameter, we get polarization in the corresponding plane which is traced out by pushing the wheel straight along the axle.

If, while the wheel is pushed along, it also rotates, a point on the tire will move as if circularly polarized; this becomes elliptical if the wheel has spokes of different length at right angles to each other: and in both cases, the Period is the time it takes the point on the tire to make one turn, and the Wave-length is the length of the axle along which the wheel advances while the point makes one complete revolution.

Polarization may be produced by reflection of light at a suitable angle from a surface, or by transmission through certain crystals (as Iceland-spar) specially cut and prepared, and then called Nicol prisms: the way in which these prisms produce it may be illustrated by the stream of water from the hose; point it at a picket fence and wag the nozzle rapidly up and down—the water will pass freely through the spaces between the pickets, and if we were on the other side of them, we should see only the effects, just as we should see only

polarized light in a vertical plane after it had passed through the prism held in a particular way; similarly, if the hose were wagged from side to side while pointed at a rail fence, the water would go through—polarization in a horizontal plane: but if, in the case of the picket fence, especially with the slats quite close, the hose were moved from side to side quickly, little or no water will pass through—it merely splashes against the pickets as against a solid wall; and so when we turn the Nicol prism at right angles to the position in which it formerly let light through, it will now quench it. A circular or elliptical motion of the nozzle—that is, corresponding polarization—will allow a little water to get through either picket or rail fence at all points of the circuit; and this is also the case with those crystals that produce double refraction and circular and elliptical polarization; light gets through them, however turned—faintly in some positions, brightly in others—maxima and minima—just as will occur with the water and the fences.

Before proceeding with the subject proper of this article, an experiment will be described that tends to prove the electromagnetic condition to be one of strain. Many crystals have the property, naturally, of splitting a ray of light entering them, so that two rays, instead of one, emerge: it is called double refraction; it is due to the substance being more dense in one direction than another. This result—splitting an incident ray into two emergent ones—may also be produced by various means: flexure, vibration, compression—thereby artificially imparting to the substance a double refracting power it did not previously possess: thus, glass of uniform density, when pressed on opposite sides, splits a ray of light just as Iceland-spar does naturally; by mechanical means it has been forced into a state of strain; and upon relief from this, by electrical means it may again be thrown into a condition that produces double refraction.

Other substances, solid and liquid, have, by compression,

its axis must be turned by a certain angle to extinguish it again: thus the plane of the light has been twisted as shown in Fig. 358.

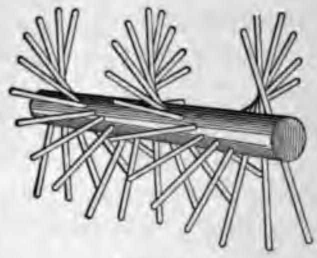

FIG. 358.

If the current be suppressed, the axis of the analyzer *A* must be turned back to the horizontal position again, in order to stop the light; if, on the contrary, the current be increased, the twist grows with it; if the polarity be reversed, so is the direction of the twist; if the glass be of greater length, this also will increase the twist: all which prove that it is the magnetic condition that causes the twist.

Other substances besides glass, placed in the magnetic field, produce this twist, but in varying degree and direction: the rotary power of iron is so great that a block of it one inch thick, magnetized to saturation, would turn the plane of polarization completely round more than a thousand times; or, to state the fact differently, a film less than one-thousandth of an inch thick would turn the plane of polarization through 360°: in contrast with this is the Earth's magnetic field, through which a beam would have to travel north and south a distance of 316 miles before its plane would suffer a twist of one degree.

Free space seems incapable of producing this rotation—the intervention of matter, and this dense and *pervaded by magnetism*, is essential.

It is also true that many natural substances—quartz and other crystals, as well as a variety of vegetable solutions—all

ase of the picket fence and the hose waved at it in two directions at right angles to each other.

When the machine is in rapid action, and the stress in the glass great, light comes through in every position in which the analyzer *A* may be turned—the strained condition of the glass has converted the plane polarized beam entering it into elliptically polarized light on emergence, whose maxima and minima intensities appear as double refraction. It is again the experience of the hose-stream and the picket fence.

To return to the subject of this article: the rotary motion called Magnetism twists the oscillatory movement called plane polarized Light into a spiral surface like the nether side of a winding stair-case. Consider Fig. 357: *M* is a section of

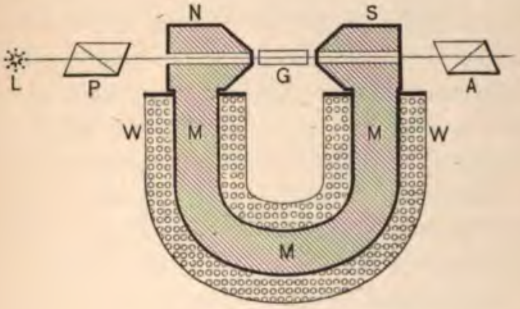

FIG. 357.

an electromagnet, whose poles *N* and *S* are bored through to give passage to a beam of light; *P* and *A* are two Nicol prisms; *G* is a block of dense glass.

The light from *L* is polarized in a vertical plane by *P*; it passes through the poles and the glass, and, if no current actuate the magnet, also through *A* when its optic axis is parallel to that of *P*; but if the prisms have their axes at right angles, it is barred at *A*: no modification of the light, however, occurs in transit—it is still polarized between *P* and *A* in a vertical plane. With the light stopped at *A*, let the current be turned on—instantly light flashes through *A*, so that

Fig. 359 shows another means of rotating polarized light by a magnetic field: N and S are the poles of an electro-magnet, the latter perforated to admit the beam, and the face

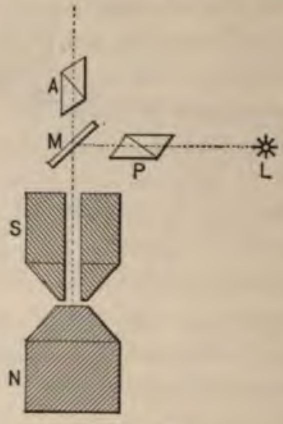

FIG. 359.

of the former polished; the light emanates from L, is polarized by the Nicol P, falls upon a partly silvered mirror M fixed at an angle of 45°, is thence thrown normally on the face of the pole N, and reflected back to A—another Nicol. If, with the magnet *in*active, this Nicol stop the light, it will cease to do so when the current is turned on—showing twist of the beam by the field, and this is further proved by the direction of the twist being changed with reversal of the poles.

201. A view of the related phenomena.—The various facts cited in this section prove, that under certain conditions, Light, Electricity, and Magnetism affect each other when in the same region of space; that they are in some way related, such as being movements of the same medium; and that they are of the same order of magnitude—like ripples that creep up the slope of a billow and there interfere, modify, or neutralize each other without perceptibly changing the aspect of the heavy roller that bears them on.

There are sounds so acute—waves of air so short and quick, that they flit past without affecting the ear; only the range of a few octaves throw it into responsive vibration—waves of medium length and frequency; while below these again, the grave sounds—waves long and slow, glide ineffectually by: so with waves in the ether; there are short ultra-violet rays that mostly produce chemical effects, middle spectrum waves that dazzle as light, and long infra-red rays that warm as heat.

Light, then, is only a sensation due to a *certain range* of ether-waves; electricity is probably a stressed displacement movement of the ether; and magnetism, no doubt, a rotary one of the same medium: but even while this last goes on, it may be combined with the second into a true undulatory motion—the electromagnetic wave. Consider a small electro-magnet in connection with a break-circuit key and source of electricity: close the key—the magnet springs into life and a field arises around it; open the key—the magnet is dead—its field gone: repeat these alternations, and the field is merely a succession of ether-waves. Light travels at the rate of 186,000 miles a second: if the key were closed once a second the waves would be 186,000 miles long, and if it could be closed 186,000 times a second, they would be one mile long; furthermore, if the magnet shrunk to atomic size, and the key could be opened and shut with such rapidity as to produce waves between one forty-thousandth and one sixty-thousandth of an inch long, there is no reason for doubting that such waves—in the ether and of the length that cause light—would produce this sensation in the eye, and that the atomic magnet would twinkle like a star. The shortest waves that can at present be produced artificially are several inches long; so that the means of exciting those that will give the ideal light yet offer a field for arduous ingenuity.

Section Two: The Ether and its Properties.

202. The varied velocity of wave-motion.—The velocity of sound varies with the medium in which it travels; roughly stated, it is least in gases, moderate in liquids, and most in solids: the properties of matter, mainly, account for such wide differences in the velocity of sound as a thousand feet a second in air and seventeen thousand feet in iron, and these properties are elasticity and density; denoting the former by c and the latter by d, the velocity for any medium will be expressed by the equation,

$$v^2 = \frac{e}{d}, \quad \ldots \ldots \tag{1}$$

or

$$v = \sqrt{\frac{e}{d}}. \quad \ldots \ldots \tag{2}$$

The velocity of luminous and electromagnetic waves has been measured, and it is enormous—186,000 *miles* a second.

Compared with sound, it seems incredible, as do the properties of the medium requisite to transmit it: from equation (2) the elasticity of such a medium must be all but infinite and its density infinitesimal, and this is the conception of the properties of the ether.

203. The ether pervades all space and matter.—Whether the ether be solid, liquid, or gas—matter so compactly massed as to form a continuous substance, or composed of fine particles with interstices equally small, is chiefly a speculation of him who writes upon the subject. In its natural state, it is conceived to pervade all space uniformly, except in matter, where it both permeates the mass uniformly and also clings to its atoms in denser layers, varying with the substance.

204. The elasticity and density of the ether.—In the conduction of Electricity, Magnetism, and Light through the Ether, its normal condition becomes disturbed—distorted: from this it recovers by a series of movements dependent upon its elasticity and density, just as is the case with tangible matter, although these qualities need not be exactly identical with those designated by the same names in such matter—only fulfilling analogous functions.

The pliability—elasticity—of the ether is different in different substances; it is called the specific inductive capacity, and is denoted by K; its value can be measured by electrostatic experiments—not absolutely, but relatively to air, in which the value is assumed to be unity: this arbitrary assumption is the basis of the artificial electrostatic system of units.

Similarly, the density of the ether varies with the substance: it is assumed to be unity in air—may be measured relatively to that by magnetic experiments, and is hence known as the magnetic permeability, and is denoted by μ; the convention that it is unity in air gives rise to the artificial electromagnetic system of units—volts, ohms, ampères, etc.

Clearly, both K and μ have to do with the velocity of electric and magnetic movements in different substances. Light, too, experiences a change of velocity in various transparent media, dependent upon the variable density of the ether in them: in air it is assumed to be unity—in all other substances it has a certain relative value to this, known as the index of refraction and denoted by n.

205. Mechanical illustration of an electro-magnetic movement.—It may dispel some of the haze surrounding a conception of the subject if an electromagnetic motion in the ether be compared with that of some visible object.

If we liken an electric current to a stream of water in a pipe, the *rate* of *flow* applies to both; so does the *quantity* that passes a given point in a specified time; the *pressure* in the water corresponds to *voltage* in the current; and *friction* of the

pipe to resistance of the conductor. But a more complete illustration is afforded by a steel spring. Consider Figs. 360 to 363: in Fig. 360, the spring S may be twisted by holding

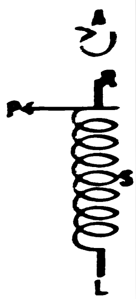

FIG. 360.

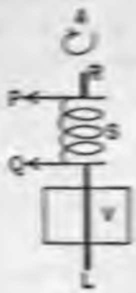

FIG. 361.

FIG. 362.

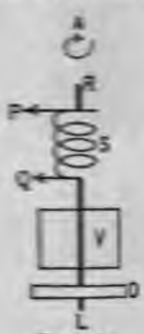

FIG. 363.

the lower end L in the left hand and twirling the upper end R between the thumb and forefinger of the right hand—the pointer P indicating the rotation; let the force applied to produce this represent electromotive force (E. M. F.), and the *rate* of rotation, the current. The flexibility of the spring—its elasticity—represents a certain capacity for twist, which may simulate electrical capacity; when the twist reaches a limit, it is analogous to the full charge in a condenser, the degree of rotation standing for the current that charged it. If suddenly released by the right hand, the spring flys back—and more, winding itself up in the opposite direction; and this, to-and-fro, several times; it is analogous to *dis*charge of a condenser, which excites a series of diminishing oscillations in the ether; and it is obvious that these depend upon the same property of both metal and medium—their elasticity; that is to say, the property of the ether is a semblance of what we call elasticity in solid substances—a property that plays a prominent part in the distortion of both, and relief therefrom. In Fig. 361, a vane of stiff paper V is attached to a rod on the spring, and a second pointer is placed at Q; viewed from above, both pointers are in line when the spring

is free of twist. Let *R* be now turned—*P* will move before *Q* and this a little in advance of *V*; on account of the air, the vane opposes resistance to rotation, but interferes scarcely at all with the beginning or ending of the motion; and this is exactly like resistance in a conductor to an electric current.

In Fig. 362, a disc of lead *D* is attached to the stem *L*; on account of its density and the way in which it is placed, it adds weight—inertia—to the system, without offering perceptible resistance to the air; whereas the vane introduced resistance without perceptible inertia—density. If, for the same volume, more weight is introduced, as for instance a disc of platinum rather than one of aluminum, this means greater inertia—more density—so that one of these terms entails the other as a synonym. On twisting *R* the pointer *P* moves first, then *Q*, and finally *D*, whose inertia must be overcome ere the rotation gains uniform velocity: so in the ether, the current *grows*, it does not jump into full strength; it creates a magnetic field which reacts upon it; and the rapid or slow growth of this field depends on the inertia—the density, of the ether in and about the conductor. This property of the ether, like its analogue in the disc, acts like a fly-wheel—retards at start, opposes little resistance while motion is uniform, but continues the movement at the finish, causing the current to fade out rather than stop at once.

Fig. 363 may represent the electromagnetic movement with all its attributes: elasticity of spring, the capacity for twist, or its analogue, electric charge; rotation of the vane against the air, resistance; and inertia of the disc, density of the medium.

Section Three: Meaning and Determination of the Physical Constant "v."

206. Nature of the proof of the electromagnetic theory of light.—"If the study of two different branches of Science [Electricity and Light] has independently suggested the idea of a medium, and if the properties which must be attributed to the medium in order to account for electromagnetic phenomena are of the same kind as those which we attribute to the luminiferous medium, in order to account for the phenomena of light, the evidence for the physical existence of the medium will be considerably strengthened. But the properties of bodies are capable of quantitative measurement. We therefore obtain the numerical value of some property of the medium, such as the velocity with which a disturbance is propagated through it, which can be *calculated* from Electromagnetic experiments, and also observed directly in the case of Light. If it should be found that the velocity of propagation of electromagnetic disturbances is the same as the velocity of light, and this not only in air, but in other transparent media, we shall have strong reasons for believing that light is an electromagnetic phenomenon, and the combination of the optical with the electrical evidence will produce a conviction of the reality of the medium similar to that which we obtain in the case of other kinds of matter, from the combined evidence of the senses.

"When light is emitted, a certain amount of energy is expended by the luminous body, and if the light is absorbed by another body, this body becomes heated, showing that it has received energy from without. During the interval of time after the light left the first body and before it reached the second, it must have existed as energy in the intervening space.

"According to the theory of undulation, there is a material medium which fills the space between the two bodies, and it is by the action of contiguous parts of this medium that the energy is passed on, from one portion to the next, till it reaches the illuminated body.

"The luminiferous medium, therefore, is, during the passage of light through it, a receptacle of energy. In the undulatory theory, this energy is supposed to be partly, potential and partly kinetic. The potential energy is supposed to be due to the distortion of the elementary portions of the medium: we must therefore regard the medium as elastic.

"The kinetic energy is supposed to be due to the vibratory motion of the medium: we must therefore regard the medium as having a finite density." (Prof. James Clerk Maxwell.)

It is here necessary to form some mental picture of an electromagnetic wave: there is an electric movement along a wire, which may be uniform—or wax and wane—or alternate in direction. There is another that oscillates between the knobs of a conductor when a Leyden jar is discharged; consider Fig. 364: the metal plates *A* and *B* are fixed to brass

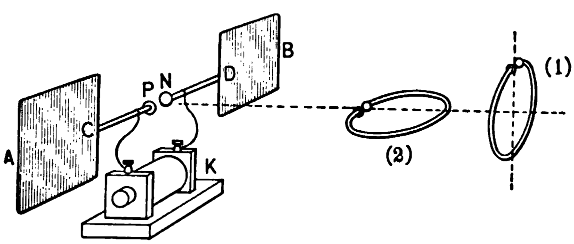

FIG. 364.

rods *C* and *D* which terminate in the knobs *P* and *N*; this system is connected with an induction-coil *K*. When a spark passes between the knobs, it is not *one* snap, and all over; but a surging to and fro from knob to knob with decreasing intensity until all energy is spent; these are electric oscillations,

Section Three: Meaning and Determination
Constant "v."

206. Nature of the proof of the electro of light.—" If the study of two different br [Electricity and Light] has independently su of a medium, and if the properties which m to the medium in order to account for elect nomena are of the same kind as those whicl the luminiferous medium, in order to acco nomena of light, the evidence for the phys the medium will be considerably strength properties of bodies are capable of quantitati We therefore obtain the numerical value o of the medium, such as the velocity with wh is propagated through it, which can be *calcu* tromagnetic experiments, and also observe case of Light. If it should be found that propagation of electromagnetic disturbance the velocity of light, and this not only in transparent media, we shall have strong rea that light is an electromagnetic phenomen bination of the optical with the electrical duce a conviction of the reality of the med which we obtain in the case of other kinds combined evidence of the senses.

" When light is emitted, a certain a expended by the luminous body, and if by another body, this body becomes he has received energy from without. D time after the light left the first body a the second, it must have existed as ene space.

substance; the velocity of light has been measured again and again, and is known both for free space, or air, and for many transparent bodies; the specific inductive capacity of bodies, that is, their relative susceptibility to electromagnetic phenomena has also been measured time and oft for many substances, and from these measurements the velocity of an electromagnetic wave can be calculated; now if the luminous and the electromagnetic wave are but components of one motion of the ether, their velocities should be the same in the same substances—*and they are.* A comparison for different transparent bodies—solids, liquids, and gases—discloses the fact that both velocities are identical in some instances, very nearly alike in others, and differ considerably in only a few cases: and this is the main proof of the electromagnetic theory of light. That the three phenomena —Light, Electricity, and Magnetism—when brought together in the same field, *do* affect each other, thus proving their intimate relationship, has already been shown in Section One of this Chapter.

As experimental means have become more refined, the discrepancy between the two velocities has grown less, so that the tendency since the first experiments were made, is steadily toward proving the luminous and electromagnetic movements to be a combined motion of the ether.

207. Electrostatic and electromagnetic units in terms of Length, Time, and Mass.—The subject of units will be treated here only from the point of view necessary to illustrate the Electromagnetic Theory of Light.

Our knowledge of natural phenomena rests partly on measures of Length, Mass, and Time: the primary quantity of each of these that is chosen as a standard by which to measure all other amounts may (and does) vary with each nation; but in the scientific community of all countries, the metrical system is generally used—the Centimetre for the unit of Length, the Gramme for the unit of Mass, and the

Second for the unit of Time; the initial letters of these words hence giving the name to the system, C.G.S. units.

But for the purpose in view, it will be more suitable to treat the quantities themselves in their fullest generality, as Length, Mass, and Time, denoted respectively by *L*, *M*, *T*.

From these flow our conceptions of other physical quantities; ***Area***, as the square of a length, L^2; ***Volume***, as its cube, L^3; ***Velocity***, as a rate of motion, evidently a length divided by a time, that is,

$$\frac{L}{T} = L \div T = L \, . \, T^{-1}; \quad . \quad . \quad . \quad . \quad (3)$$

Acceleration, that is, a ***change in a velocity***, which therefore is the velocity itself divided by the time for which the change is to be indicated, or

$$L \, . \, T^{-1} \div T = L \, . \, T^{-2}; \quad . \quad . \quad . \quad . \quad (4)$$

Force, as the moving spirit of a mass, and if the motion of this mass changes, that is, undergoes acceleration (decrease of motion being minus acceleration), the force suffers a corresponding change, and hence becomes an index of the motive power, whence force is suitably represented by the mass multiplied by the acceleration of its motion, that is,

$$M \, . \, L \, . \, T^{-2}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Work, as the result of force acting upon a mass along a length, that is,

$$M \, . \, L^2 . \, T^{-2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Thus, successively, from Velocity we derive the idea of Acceleration; from this the conception of Force; and from the latter the definition of Work: each being represented by a certain value and combination of the elementary quantities—Length, Mass, and Time.

The electromagnetic movements of the ether constitute

one of the Forces of Nature which will impart Velocity to a Mass and thus perform Work, precisely as the Force of Heat in steam will draw a train with varying speed (Acceleration) along a track; so that the results of electric and magnetic action can be represented by the same elementary quantities —Length, Mass, and Time—as the efforts of mechanical and physical force. But while we measure these latter forces with a single system of units, the ethereal force has a double standard—the electrostatic and the electromagnetic—each based, as a starting point, on a separate and distinct conception of the abode of the Force; the first has the force exerted between two quantities of electricity—such as two equal charges on metal balls—as its basis; and the second has the force between two magnet poles for its foundation. In each system, a variety of units arises whose names usually express the peculiarity of their origin: for the illustration in view, some of these units common to both systems will be traced from their sources, that is, from the conception of Force expressed above in Length, Mass, and Time. Incidentally, it may be stated that when these are made specific by the introduction of the C.G.S. units, a third system has arisen—the Ohm, Ampère, Volt, Coulomb, Farad, Watt, series of units; but with these we have no necessary concern here.

To return to the electrostatic and electromagnetic systems: the units common to both which will be specially considered are: Quantity, Potential, Capacity, and Resistance; and, except the first, each of these is based on the same primary factors, thus: Potential in both systems rests on Work and Quantity; Capacity, on Potential and Quantity; and Resistance, on Potential and Current. In the electromagnetic system, Quantity rests on Current and Time—in the electrostatic, on Force and Distance.

The electrostatic system and its derivatives.

Quantity, Q: let Q and Q' represent the quantities of electricity on two metal balls separated by the distance L from

Second for the unit of Time; the initial letters of these w
hence giving the name to the system, C.G.S. units.

But for the purpose in view, it will be more suitab
treat the quantities themselves in their fullest generalit
Length, Mass, and Time, denoted respectively by L, M,

From these flow our conceptions of other physical q
tities; *Area*, as the square of a length, L^2; *Volume*, as its
L^3; *Velocity*, as a rate of motion, evidently a length divide
a time, that is,

$$\frac{L}{T} = L \div T = L \, . \, T^{-1}; \quad . \quad . \quad . \quad .$$

Acceleration, that is, a *change in a velocity*, which theref
the velocity itself divided by the time for which the cha
to be indicated, or

$$L \, . \, T^{-1} \div T = L \, . \, T^{-2}; \quad . \quad . \quad .$$

Force, as the moving spirit of a mass, and if the motion
mass changes, that is, undergoes acceleration (dec
motion being minus acceleration), the force suffer
responding change, and hence becomes an index o
tive power, whence force is suitably represented by
multiplied by the acceleration of its motion, that is

$$M \, . \, L \, . \, T^{-2}; \quad . \quad . \quad . \quad .$$

Work, as the result of force acting upon a ma
length, that is,

$$M \, . \, L^2 \, . \, T^{-2}. \quad . \quad . \quad .$$

Thus, successively, from Velocity we derive th
celeration; from this the conception of Force;
latter the definition of Work: each being rep
certain value and combination of th
Length, Mass, and Time.

The electromagnetic n

Capacity, A: a specific quantity of electricity on a sphere has inalienably linked to it a definite potential; if the sphere expands, the same quantity of electricity being spread over it must be at a lower potential, and if it contracts, the potential rises: the sphere, therefore, has a certain Capacity A for a fixed quantity Q at a definite potential V; that is,

$$Q = A \,.\, V, \quad \ldots \ldots \quad (17)$$

or,

$$A = \frac{Q}{V}; \quad \ldots \ldots \quad (18)$$

substituting in this the values from (12) and (16), it becomes

$$A = \frac{M^{\frac{1}{2}} \,.\, L^{\frac{3}{2}} \,.\, T^{-1}}{M^{\frac{1}{2}} \,.\, L^{\frac{1}{2}} \,.\, T^{-1}}, \quad \ldots \ldots \quad (19)$$

or

$$A = L; \quad \ldots \ldots \quad (20)$$

that is, the capacity is directly dependent on a linear measure —the radius of the sphere, as is otherwise evident.

Resistance, R: in any conductor, the current, C, which may traverse it, is dependent on the difference of potential, V, between its ends and the inherent obstructive nature of the material itself—its Resistance, R; that is, the current varies directly as the potential, and inversely as the resistance, or

$$C = \frac{V}{R}, \quad \ldots \ldots \quad (21)$$

whence

$$R = \frac{V}{C}; \quad \ldots \ldots \quad (22)$$

now the volume or quantity, Q, of water that passes a point in a stream is equal to its rate of flow per unit of time—that

is, the current—multiplied by the duration of flow; and it is the same with a current of electricity; that is,

$$Q = C \,.\, T, \quad \ldots \ldots \quad (23)$$

whence

$$C = \frac{Q}{T}; \quad \ldots \ldots \quad (24)$$

substituting in this the value of Q from (12), it becomes

$$C = \frac{M^{\frac{1}{2}} \,.\, L^{\frac{3}{2}} \,.\, T^{-1}}{T}, \quad \ldots \ldots \quad (25)$$

or,

$$C = M^{\frac{1}{2}} \,.\, L^{\frac{3}{2}} \,.\, T^{-2}; \quad \ldots \ldots \quad (26)$$

then putting in (22) the value of V from (16) and that of C from (26), equation (22) becomes

$$R = \frac{M^{\frac{1}{2}} \,.\, L^{\frac{1}{2}} \,.\, T^{-1}}{M^{\frac{1}{2}} \,.\, L^{\frac{3}{2}} \,.\, T^{-2}}; \quad \ldots \ldots \quad (27)$$

that is,

$$R = L^{-1} \,.\, T. \quad \ldots \ldots \quad (28)$$

The Electromagnetic System of Units in terms of Length, Mass, and Time. Quantity, Q: the quantity of electricity in a current of definite duration is evidently equal to the rate of flow—the strength of current, multiplied by the time it lasts, that is,

$$Q = C \,.\, T; \quad \ldots \ldots \quad (29)$$

but the strength of current and intensity of the magnetic field it produces, have a constant ratio—as the one waxes or wanes, the other gains or loses intensity, and thus a determinate value of the latter becomes an index of the former: now a field produced by a current may be duplicated in every respect by the pole of a steel magnet, so that this may become indirectly a measure of the current; and the force ex-

erted between the poles of two steel magnets is expressed (as previously proved in this Treatise) by

$$F = \frac{m \, . \, m'}{L^2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (30)$$

in which m and m' represent the strength of the poles respectively and L the distance between them.

Thus the value of Q is traced finally to the force between two poles of permanent magnets: to retrace these steps and introduce at each the dimensions of Length, Mass, and Time, let $m = m'$, then

$$F = \frac{m^2}{L^2}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (31)$$

whence

$$m = \sqrt{F \, . \, L^2}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (32)$$

substituting in this the value of F from (5), it becomes

$$m = \sqrt{(M \, . \, L \, . \, T^{-2})(L^2)} = \sqrt{M \, . \, L^3 . \, T^{-2}}, \quad . \qquad (33)$$

or

$$m = M^{\frac{1}{2}} \, . \, L^{\frac{3}{2}} \, . \, T^{-1}. \quad . \quad . \quad . \quad . \quad . \quad . \qquad (34)$$

If the force, F, exerted between two equal poles as denoted by (5) be divided by the strength of pole, m, as given in (34), the intensity, H, of the field is obtained, that is,

$$H = \frac{M \, . \, L \, . \, T^{-2}}{M^{\frac{1}{2}} \, . \, L^{\frac{3}{2}} \, . \, T^{-1}}, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (35)$$

or,

$$H = M^{\frac{1}{2}} . \, L^{-\frac{1}{2}} \, . \, T^{-1}. \quad . \quad . \quad . \quad . \quad . \qquad (36)$$

The current is evidently equal to the intensity of field multiplied by the length over which it extends, that is,

$$C = H \, . \, L; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (37)$$

or, by means of (36),

$$C = (M^{\frac{1}{2}} \, . \, L^{\frac{1}{2}} \, . \, T^{-1})L, \quad . \quad . \quad . \quad . \quad . \qquad (38)$$

or

$$C = M^{\frac{1}{2}} . L^{\frac{1}{2}} . T^{-1}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (39)$$

and, finally, substituting this value of C in (29), we have

$$Q = M^{\frac{1}{2}} . L^{\frac{1}{2}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (40)$$

Potential, V: in the electromagnetic, as in the electrostatic, the potential is equal to work divided by quantity, that is,

$$V = \frac{W}{Q}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (41)$$

introducing into this the value of W from (6) and that of Q from (40), it becomes

$$V = \frac{M . L^2 . T^{-2}}{M^{\frac{1}{2}} . L^{\frac{1}{2}}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad (42)$$

or,

$$V = M^{\frac{1}{2}} . L^{\frac{3}{2}} . T^{-2}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (43)$$

Capacity, A: this, too, like the similar unit in the other system, has for its basis, the quotient of quantity by potential, that is,

$$A = \frac{Q}{V}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (44)$$

introducing the value of Q from (40) and that of V from (43), we have

$$A = \frac{M^{\frac{1}{2}} . L^{\frac{1}{2}}}{M^{\frac{1}{2}} . L^{\frac{3}{2}} . T^{-2}}, \quad . \quad . \quad . \quad . \quad . \quad (45)$$

that is,

$$A = L^{-1} . T^2. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (46)$$

Resistance, R: likewise here, resistance has the same fundamental factors as in the electrostatic system—the quotient of potential by current—that is,

$$R = \frac{V}{C}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (47)$$

substituting in this the value of V from (43) and of C from (39), it becomes

$$R = \frac{M^{\frac{1}{2}} \,.\, L^{\frac{3}{2}} \,.\, T^{-2}}{M^{\frac{1}{2}} \,.\, L^{\frac{1}{2}} \,.\, T^{-1}}, \quad . \quad . \quad . \quad . \quad . \quad . \qquad (48)$$

whence

$$R = L \,.\, T^{-1}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (49)$$

208. The significance of "v," the ratio of the two sets of units.—Collecting into one view the symbolic expressions of the preceding units common to both systems, and dividing the electrostatic by the electromagnetic, the result appears in the accompanying Table 27: columns (1), (2), and (3) contain the equations just deduced in L.M.T.—dimensions; column (4) is the indicated division of (2) by (3); column (5) is column (4) reduced to its lowest terms, and this in every instance contains only the dimensions L and T: now Length divided by Time is essentially of the nature of a Velocity, and this is the case in equations (50) and (52); by taking the reciprocals of (51) and (53), the same result appears, "v" simple and square in reciprocal: but the matter may be otherwise stated as follows:

One electromagnetic unit of Quantity

$$= v \text{ electrostatic units;} \quad . \quad . \quad . \quad . \qquad (54)$$

One electromagnetic unit of Capacity

$$= v^2 \text{ electrostatic units;} \quad . \quad . \quad . \quad . \qquad (55)$$

v electromagnetic units of Potential

$$= \text{one electrostatic unit;} \quad . \quad . \quad . \quad . \qquad (56)$$

v^2 electromagnetic units of Resistance

$$= \text{one electrostatic unit.} \quad . \quad . \quad . \quad . \qquad (57)$$

Thus, it is always a *velocity* that is obtained in passing from consideration of electricity in a quiet state—as a static

TABLE 27.

Unit. (1)	Electrostatic. (2)	Electromagnetic. (3)	Ratio. (4) (5) (6)
Quantity, Q..........	(12); $Q = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}$	(40); $Q = M^{\frac{1}{2}}L^{\frac{1}{2}}$	$Q = \frac{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-1}}{M^{\frac{1}{2}}L^{\frac{1}{2}}} = \frac{L}{T} = v$. . . . (50)
Potential, V..........	(16); $V = M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}$	(43); $V = M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}$	$V = \frac{M^{\frac{1}{2}}L^{\frac{1}{2}}T^{-1}}{M^{\frac{1}{2}}L^{\frac{3}{2}}T^{-2}} = \frac{T}{L} = \frac{1}{v}$. . . . (51)
Capacity, A..........	(20); $A = L$	(46); $A = L^{-1}T^2$	$A = \frac{L}{L^{-1}T^2} = \frac{L^2}{T^2} = v^2$ . . . (52)
Resistance, R..........	(28); $R = L^{-1}T$	(49); $R = LT^{-1}$	$R = \frac{L^{-1}T}{LT^{-1}} = \frac{T^2}{L^2} = \frac{1}{v^2}$ . . . (53)

charge upon a metal sphere, which is the origin of the electrostatic system of units—to consideration of it in motion—as a current along a wire, which is essentially at the foundation of the electromagnetic system: therefore, the natural inference is, that if a multitude of small charged bodies should sweep through space with the speed of an electric current, they would in effect constitute such a current; indeed this is realized in the discharges of high vacua, where the residual particles of matter, burdened with electricity, stream from the cathode to the anode in a luminous band that is waved about by means of a magnet as if it were a flexible wire carrying a current.

And again, this fact has been proved directly by charging a gilt ebonite disc with static electricity and giving it rapid rotation, when it affected a suspended magnetic needle as a feeble circular current would.

The velocity of column (6) is the great physical constant "*v*"—the velocity with which, according to Maxwell, an electromagnetic disturbance is propagated through space; that is, "if a sudden difference of magnetic potential be caused at any point, the disturbance due to it will be felt at any other point after an interval which, on being compared with the distance between the points, shows the disturbance to have been propagated with this velocity."

While it is possible to devise means of measuring this velocity directly, still "the indirect method of comparison of units is as certainly a measure of the velocity of the disturbance, and is capable of far greater accuracy than is ever likely to be attained by the direct method."

The quantity "*v*" is of such importance to the theory under consideration, that further illustration of it (following in effect Maxwell) will be given: let there be two small gilt balls fixed on little carriages that move upon parallel rails separated by a short distance; let the balls be charged with the same quantity of the same kind of electricity; while at rest,

there will be a certain force of repulsion between them; now start the carriages in rapid flight—such velocity, in fact, that the charged balls become elements of electric currents coursing along the rails; at this stage, their repulsion—when at rest—has given way to attraction, as elements of currents flowing in the same direction, and the speed that has wrought this change is the velocity "v." The following is a proof of this statement: let a represent two lengths of parallel currents whose numerical values are c and c' in electromagnetic measure, and b the distance between them; as they flow in the same direction, the attractive force f is

$$f = \frac{2 \cdot a \cdot c \cdot c'}{b} \quad \ldots \ldots \quad (58)$$

Let the length a be so chosen that

$$2a = b, \text{ then } f = c \cdot c'. \quad \ldots \ldots \quad (59)$$

If v be the number of electrostatic units in one electromagnetic unit, then we have to prove that v is a velocity.

The quantity of electricity transmitted by a current c in a time t, is $c \cdot t$ in electromagnetic measure, and therefore $v \cdot c \cdot t$ in electrostatic measure, since one of the former is v-times the latter. Let q and q' be the static charges imparted to two gilt balls in the time t by the currents c and c' respectively; d the distance separating the balls; and f' the repulsive force between them—repulsive, because electricity of the same kind; then the charges on the balls in electrostatic measure are:

$$q = v \cdot c \cdot t, \quad \ldots \ldots \quad (60)$$

and

$$q' = v \cdot c' \cdot t, \quad \ldots \ldots \quad (61)$$

and the repulsive force is

$$f' = \frac{(v \cdot c \cdot t)(v \cdot c' \cdot t)}{d^2} = \frac{q \cdot q'}{d^2}, \quad \ldots \quad (62)$$

or

$$f' = \frac{v^2 . t^2 . c . c'}{d^2} . \quad . \quad . \quad . \quad . \quad . \quad (63)$$

Let the distance d be varied until this electrostatic repulsion equals the electromagnetic attraction, that is $f = f'$, whence from (59) and (63),

$$c . c' = \frac{v^2 . t^2 . c . c'}{d^2}, \quad . \quad . \quad . \quad . \quad . \quad (64)$$

or

$$d^2 = v^2 . t^2, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (65)$$

or,

$$d = v . t, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (66)$$

or,

$$v = \frac{d}{t}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (67)$$

that is, v, the number of electrostatic units in one electromagnetic unit, is equal to a distance d divided by a time t—which is a *velocity;* and the absolute magnitude of this is the same whatever the specific units adopted.

209. The specific inductive capacity (K) and magnetic permeability (μ).—A cubic centimetre of gold, silver, or any other substance placed in counterpoise to an equal volume of distilled water at 4° C., will have a different weight from it: regarding the water as a standard of comparison, the relative weights of other substances are expressed by a *ratio,* called their specific gravity, as, for instance, 19.3 for gold, 7.8 for iron, and 2.1 for sulphur.

So, with the Specific Inductive Capacity and the Magnetic Permeability—they are *ratios,* denoted by K and μ respectively—the former to express the susceptibility of matter to electrical phenomena; the latter, to magnetical.

Consider a Leyden jar: it is essentially a glass bottle

coated e and out with tin-foil; it may be charged with electricit nd has a maximum capacity, beyond which there will be verflow. If two concentric rolls of tin-foil, identical w ose of the jar, be separated by a space filled with air at a perature of 0° C. and pressure of 760 mm., this, also, w nstitute a Leyden jar—an air jar, if one may so call it— lefinite electrical capacity; let the quantity that will charge it to the full be denoted by unity: then by successively replacing the air between the two rolls of tin-foil by an equal thickness of mica, glass, ebonite, etc., it may be seen whether the same quantity of electricity—or more, or less—that charged the air jar to the utmost, will do the same for the others; and it will be found that it will not, but that about six times as much is necessary for the mica jar, three times as much for the glass jar, twice as much for the ebonite jar, and so on; that is, these numbers—known as Dielectric Constants—the ratio K—express the specific capacity of mica, glass, and ebonite (compared with air as unity) to receive electric strain; and the substances themselves—the recipients of strain between the tin-foil conductors—are called Dielectrics.

Similarly (to illustrate Magnetic Permeability) consider a tubular coil of wire—a solenoid, alive with electricity: the core is pervaded by a magnetic field of definite intensity represented by a specific number of lines of force—the air in the core admits that number and no more. Let a cylinder of cobalt fill the core, and more lines of force will gather into it than when only air was there—the field will be more intense. Replace the cobalt by a cylinder of nickel of equal size, and still more lines of force will crowd in upon this with a resulting stronger field. Finally, insert a rod of soft iron of like dimensions and all the lines of force possible will seek transit through it—the field will be the most intense attainable. This varying field being measured when iron, nickel, and cobalt successively fill the core, affords numbers, which, compared with air taken as unity and a standard, become *ratios* denoted

by μ, that express the relative permeability of these substances to magnetic induction.

210. Indirect methods of determining "v."—The velocity of wave-motion depends on two properties of the medium in which it occurs—the elasticity and density: neither of these has been determined for the ether by itself, only for its condition in connection with other matter, and this only in relative measure for different substances, compared with air.

In all media, the velocity of wave-motion is expressed by the formula,

$$v = \sqrt{\frac{\text{elasticity}}{\text{density}}}. \quad . \quad . \quad . \quad . \quad . \quad (68)$$

so that if we consider the elasticity of a substance, its facility to transmit motion, it then is in direct opposition to its capacity for strain, that is, to its specific inductive capacity—its dielectric constant, K; for if ebonite will admit more electricity than air does to charge it to the same potential, and glass more than ebonite, and mica still more, it is clear that their specific inductive capacity—their retention of strain—their *un*willingness to transmit motion, is in this order, and therefore inversely to their electrical elasticity: hence, representing electrical elasticity by k, we have

$$k = \frac{1}{K}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (69)$$

Coincident with every electrical movement is the magnetic field, spreading out at right angles to the direction of the current, retarding its growth as well as preventing its sudden collapse—a kind of fly-wheel: and the varied degree of this in different media is the magnetic permeability, μ; and since it acts as a drag, it performs the function of inertia—a synonym of density.

Thus, for electromagnetic wave-motion, we have in ether the specific inductive capacity, K, or its reciprocal, rather,

$\frac{1}{K} = k$, esponding to elasticity in other media, and magnetic ability, μ, answering to density in those substanc hat introducing these quantities into (68), it becom

$$v = \sqrt{\frac{k}{\mu}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (70)$$

substituti this the value of k from (69), we have

$$v = \sqrt{\frac{\frac{1}{K}}{\mu}} = \sqrt{\frac{\frac{1}{K}}{\frac{\mu}{1}}} = \sqrt{\frac{1}{K} \times \frac{1}{\mu}} = \sqrt{\frac{1}{K \cdot \mu}}$$

$$= \frac{1}{\sqrt{K \cdot \mu}}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (71)$$

Relative numerical values of K and μ have been determined time and again for almost all substances; k thence becomes known by (69); its ratio to μ is the velocity of an electromagnetic wave in the ether dependent upon the electrical elasticity and magnetic density of the medium as expressed by the general principle of equation (68): but K is determined in electrostatic measure and μ in electromagnetic, hence the ratio of k to μ (since k is deduced from K) is in reality the ratio of the two systems of units in Table 27, so that the v obtained there as that ratio is identical with the v resulting from equation (71): and thus it becomes clear how comparison of the units in both systems of measure affords the velocity of an electromagnetic wave in the ether.

Before stating methods of comparing the units in both systems, it may be well to fix the ideas about measuring K. by a single illustration. In Fig. 366, P and P' are two metal plates with wires a and b terminating in the small balls that are separated by an air-gap at G; M and M' are two similar plates

parallel to the former but not in contact with them; from M and M' extend parallel wires ww', thirty centimetres apart, to a distance of more than a thousand centimetres; at their ends the flexible wires f and f' connect with circular metal plates N and N' about twenty centimetres diameter; these plates are so arranged that the distance between them may be varied without disturbing their parallelism; T is a vacuum-tube spanning the wires, and which may be moved along them.

The balls at G being connected with the poles of an induction-coil, or to the coatings of a Leyden jar, at L, when discharge takes place, a spark jumps the gap with a succes-

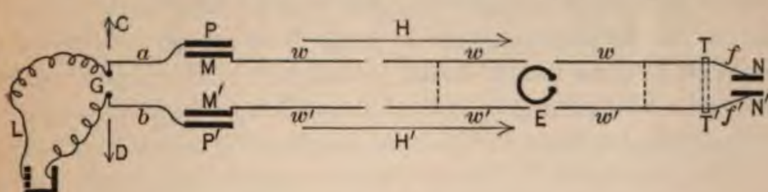

FIG. 366.

sion of diminishing electrical oscillations between the balls as indicated by the arrows C and D: coincident with these arises the magnetic field by a corresponding series of pulses along a and b, charging the plates P and P', which, in turn, by induction across the air-space, charge M and M', and thus continue onward along the wires the succession of magnetic waves indicated by the arrows H and H'. These waves have points of maxima and minima—characteristics of all undulatory motion: according to the capacity for strain of the medium between N and N'—whether of air, glass, sulphur, or some other substance, such also will be the degree of charge the plates N and N' will accept, with corresponding length of wave; for this depends upon the electrical capacity of the space between N and N'. Thus, the length of wave being measured, becomes an index of the specific inductive capacity of the substance between N and N', that is, a value of K.

To mea[illegible] the length of wave, the vacuum-tube T is slid along t[illegible]ires—it will glow at the summit of each ventral segmen[illegible]le on each side of it, and become dark at a node.

To [illegible]pare units of the electrostatic system with those of the [illegible]omagnetic, the general principle of all methods is to me[illegible]re the same thing in both; different numerical values are [illegible]hus obtained, and the ratio of these is in specific terms the velocity v, which was obtained in Table 27 in general terms. The following three methods will illustrate the procedure:

First, by measuring *Quantity:* the quantity of electricity that a Leyden jar contains, is obtained in electrostatic measure from the difference of potential between its coatings as indicated by an electrometer; it is found in electromagnetic measure by discharging the jar through a ballistic galvanometer, and the first swing of its needle affords data for calculating the quantity of current that passed through the coil: the ratio of the numbers representing the quantity in both measures is v.

Second, by measuring *Potential:* this, as in the first case, is done directly in electrostatic measure by means of an electrometer connected with the two coatings of a Leyden jar; to obtain the same in electromagnetic measure, it is known that electromotive force (E.M.F.), or potential difference, is equal to the product of current and resistance, both of which are readily determined; and then, as in the first case, the ratio of the potential by both systems is v.

Third, by measuring *Force:* that of electrostatic attraction between two oppositely charged discs is balanced against the electromagnetic repulsion between two spiral bands of known resistance through which currents flow; and again the ratio of the force by both is v.

The result of the best determinations of v—the velocity of an electromagnetic wave in air—by the various methods described, is 2.9857×10^{10} centimetres per second; and

the most accurate measurement of the velocity of light in air is 3.0031×10^{10} centimetres per second: the difference being only 0.017, it is safe to say that, in view of the proven intimate relationship otherwise existing between luminous and electromagnetic phenomena, they are due to a compound motion of the same medium.

211. Direct methods of measuring *v*.—1st: when electromagnetic waves arise from the sparks of a Leyden jar, they travel onward as indicated by the arrows *HH'* in Fig. 366; meeting any circuit, as, for instance, the small loop of wire *E* with an air-gap, they induce in it a current which leaps the gap as a spark; if the instant of the two flashes be noted, that at *G* and that at *E*, and their distance apart be measured, we evidently have the factors that determine the velocity of the waves. But the interval between the primary and the secondary spark is so small that they appear simultaneously to all methods of observation.

2d: referring again to Fig. 366, if the electromagnetic undulations be reflected back upon themselves by means of a large metal screen placed at *N* normally to their direction, this will convert them into standing waves; their nodes and crests may be explored with a glow-lamp, and the length of wave determined; their frequency may be calculated from certain (obtainable) data regarding their source, and hence *v* is found from the length of wave and its frequency per second.

212. A luminous and an electromagnetic undulation have the same velocity in transparent media.—In order to establish this fact, it will be necessary to explain what is meant in Optics by the Index of Refraction. Consider Fig. 367: it represents a graduated circle upon which two arms *ON* and *OP* move independently as radii; attached to each is a graduated ruler, which moves with the arm so as to be always perpendicular to the vertical diameter *AD*; at *B* is a semi-cylinder of glass—it may be solid, or hollow, and in the

latter case may be filled with liquid, or even gas, by having an air-tight cover; a mirror *M* and screen *N* are fixed on one arm, and a reflector *P* on the other; these attachments, together with *B*, are all set normally to the plane of the circle, the surface of *B* being at its center.

When a ray of sunlight is reflected by the mirror, it proceeds through a hole in *N*, strikes the surface of *B*, and passes in part through it, and in part on the opposite side of *AO* by reflexion: the part that passes through *B* is not, however, a

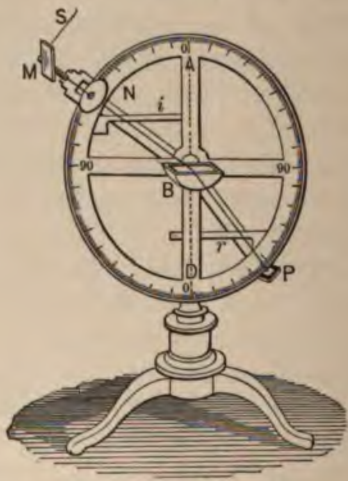

FIG. 367.

prolongation of the straight course from *N* to *O*, but is deviated, so that the reflector *P* will have to be moved in order to receive the transmitted image of the ray; and the amount of motion of *P* will vary with the substance at *B*—it will be one thing with solid glass, another with diamond, still another with water in a hollow vessel, and again different with other liquids or gases.

Under all circumstances, the angle of incidence *i* and of refraction *r*—the two directions of the ray—are observed on the circle, and their sines are read off on the rulers: it is found

by experiment that however these angles may vary, their *ratio* is constant for the same substance, while differing from one substance to another; this ratio is called the Index of Refraction and is denoted by n, so that

$$n = \frac{\sin i}{\sin r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (72)$$

If, while retaining the same angle of incidence i, we place various substances successively at B, each more dense than the preceding, the *angle* of refraction r will steadily *decrease* with each new substance; hence it is inferred that the *density* of the substance constitutes some barrier to the free passage of the ray. Since an *in*crease of density entails a *de*crease of r, we have from (72) a corresponding *in*crease of n—that is, n varies directly as the *obstructive* property of the medium. The converse of this may be stated as the facility to transmit the ray—the *non*-obstructiveness of the medium, which therefore must vary inversely as n—that is, the velocity v of a luminous wave in any medium is inversely as n, or

$$v = \frac{1}{n}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (73)$$

This is entirely analogous to (71), and the conditions and reasoning that lead up to the two equations are similar in both cases, the one for Light—the other for Electricity: hence if these be due to a compound motion of the ether, their velocities must be the same in each medium; that is, equating the value of v in (71) and (72), we have

$$\frac{1}{\sqrt{K.\mu}} = \frac{1}{n}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (74)$$

or,

$$n = \sqrt{K.\mu}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (75)$$

or,

$$n^2 = K.\mu. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (76)$$

As pre[illegible]y explained, both n and K can be measured relatively to [illegible] the former for Light—it is the Index of Refraction, the[illegible]ter for Electricity—it is the Specific Inductive Capaci[illegible], the Magnetic Permeability, is considered constant—[illegible] not affect relative values—and therefore, for these we [illegible]y write

$$n^2 = K. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (77)$$

Table 28 gives the values of n^2 and K for a few substances.

TABLE 28.

(1) Substance.	(2) State.	(3) K.	(4) n^2	(5) Differences.
Glass................	Solid.	3.162	2.796	0.366
Sulphur..............	Solid.	4.151	4.024	0.127
Paraffin..............	Solid.	2.320	2.330	0.010
Bisulphide of carbon..	Liquid.	1.812	2.606	0.794
Carbonic acid.........	Gas.	1.000	1.000	0.000
Hydrogen............	Gas.	1.000	1.000	0.000

That there should be the agreement in the velocities indicated by the small differences of column (5) is most remarkable.

"In some cases the speeds are accurately the same, in no case are they entirely different; and in those cases where the agreement is only rough, an efficient and satisfactory explanation of the difference is to hand in the very different lengths of wave which have at present been submitted to experiment.

"To compare the speeds properly, we must either learn to shorten electrical waves, or to lengthen light waves, or both, and then compare the two things together when of the same size. It cannot be seriously doubted that they will turn out identical." (Prof. O. J. Lodge.)

Thus, the vital question—Are Light and Electricity one and the same movement?—is answered almost irrefutably in the affirmative.

213. A method of making the L.M.T. indices whole numbers.—By referring to equations (7) and (30)—both expressions for Force, the former in the electrostatic system and the latter in the electromagnetic, and each the foundation of its respective system—it will be seen that no factor enters to represent the medium in which the force is exerted; but this cannot be ignored, for it makes a great difference whether the entire space between the two centers of force be pervaded by common air, or pure oxygen, or some other medium in a solid, liquid, or gaseous state: all these will change the degree of force that may be measured, and variously. From this omission to consider the effect of the medium in the basic unit of each system, have arisen those fractional dimensions in Table 27: they are incongruous and without physical meaning. If, however, in equation (7) K be introduced as the dielectric constant of the medium, and in (30) μ as the permeability, the exponents might be made rational if the dimensions of K and μ were known; but they are not: it has been shown, however, that the exponents can be made rational, "and the two sets of units brought into agreement by *assuming* that the product $K\mu$ has the dimensions of the reciprocal of the square of a velocity, or

$$v = \frac{1}{\sqrt{K \cdot \mu}}, \qquad (78)$$

or

$$K \cdot \mu = \frac{1}{v^2}." \qquad (79)$$

(Prof. RÜCKER).

In vol. 34 of the London *Philosophical Magazine*, there is an elaborate article by Prof. W. Williams on a method of expressing by dimensional formulæ—that is, in terms of L.M.T.—all the quantities that arise in electromagnetic phenomena, in such way that these formulæ become the

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(1) Substance
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the affirmative.

Let r be measured along the axis of X, then, since δs is always an element at right angles to r, δs will be measured along Y or Z. If these directions (X, Y, Z) be carried *along with r* —that is, if we take instantaneous axes at every point of the arc—the axes bearing the same relation to the radius and tangent at every point, we get

$$\delta\theta = \frac{\delta Y}{X}, \quad \ldots \ldots \quad (83)$$

and

$$\theta = \frac{\Sigma\delta Y}{X}. \quad \ldots \ldots \quad (84)$$

To express these dimensionally, we have to omit the sign of summation Σ; for a dimensional formula expresses the nature of a quantity, not its magnitude; and the same formula must therefore apply to both θ and $\delta\theta$; the dimensions of θ and $\delta\theta$ are, then YX^{-1}; and from this may be easily derived the dimensional formula of *angular* velocity, *angular* acceleration, etc.

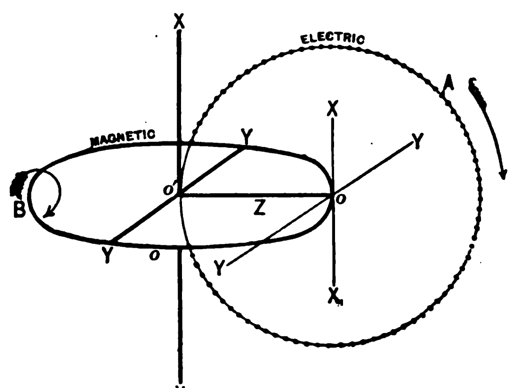

FIG. 368.

Imagine water issuing from the summit of ground that falls away gradually on every side—this is a *source;* imagine it flowing into a hole in an area that descends uniformly all

round—this is a *sink:* sources and sinks are technical terms in the analytical treatment of the flow of liquids. A vortex ring combines in itself the symbol of both source and sink, for there is an *out*ward movement on one side and an *in*ward on the other. An electromagnetic displacement likewise simulates both source and sink, and vortex motion: consider Fig. 368; the electrical displacement is round the dotted line A, while surrounding its entire circuit are circles of magnetic induction—the axes of vortex rings as indicated at B. The north pole of a magnet may be considered analogous to a source—an *out*flow: the south pole, a sink—an *in*flow.

If m and q be point sources of magnetic induction and electrical displacement respectively, the measure of each at a distance r from the sources, if the fluxes emanate equally in all directions, is:

$$B = \frac{m}{4\pi r^2}, \qquad (85)$$

and

$$D = \frac{q}{4\pi r^2}, \qquad (86)$$

where B and D are the densities of the fluxes over spherical surfaces enclosing the sources. Let $B = \mu \, . \, H$ and $D = K \, . \, E$, where μ and K represent physical properties of the medium; then from (85) and (86),

$$H = \frac{1}{\mu} \cdot \frac{m}{4\pi r^2}, \qquad (87)$$

and

$$E = \frac{1}{K} \cdot \frac{q}{4\pi r^2}. \qquad (88)$$

Now H and E express the strength of the fields produced by the fluxes m and q at the distance r: hence $\frac{m}{\mu}$ and $\frac{q}{K}$ express

the strength of the sources. Multiplying (87) and (88) respectively by m and q, we get

$$m \,.\, H = \frac{1}{\mu} \frac{m^2}{4\pi r^2}, \quad . \quad . \quad . \quad . \quad . \quad (89)$$

and

$$q \,.\, E = \frac{1}{K} \frac{q^2}{4\pi r^2}; \quad . \quad . \quad . \quad . \quad . \quad (90)$$

but $m \,.\, H$ is the force experienced by a magnet pole m when placed in a field of strength H, and similarly for $q \,.\, E$; hence

$$F_m = m \,.\, H = \frac{1}{\mu} \cdot \frac{m^2}{4\pi r^2}, \quad . \quad . \quad . \quad . \quad (91)$$

and

$$F_q = q \,.\, E = \frac{1}{K} \cdot \frac{q^2}{4\pi r^2}; \quad . \quad . \quad . \quad (92)$$

where F_m and F_q are respectively the forces between two poles m, or two charges q, at the distance r apart. In other words, since, in expressing the force between two poles or two charges, we have to regard each pole or charge as an isolated point source of displacement, we should regard the one pole or charge as producing radially a field of given strength and then express the force experienced by the other when placed in this field. If now, from (91) and (92) we deduce

$$m = r\sqrt{4\pi\mu F_m}, \quad . \quad . \quad . \quad . \quad . \quad (93)$$

and

$$q = r\sqrt{4\pi K F_q}, \quad . \quad . \quad . \quad . \quad . \quad (94)$$

and make *this* m and q the unit pole and unit charge instead of $m = r\sqrt{\mu F_m}$ and $q = r\sqrt{KF_q}$, as is usual, the effect is to distribute π in electromagnetic equations as a whole.

It is found, however, that all those relations into which it is now made to enter depend upon and involve the con-

sideration of circuital or radial fluxes, and π obviously enters as a plane or solid angle in connection with circles and spheres of reference: it has thus a definite physical meaning, and is always definitely related to the other quantities in the relation.

The relations made use of in deducing the dimensions of electromagnetic quantities, may exist between those of the same kind—either purely electrical, or purely magnetic; or they may be between quantities of different kinds—as between magnetic and electrical; or they may be dynamical relations.

The purely magnetical relations can be expressed by certain formulæ; so can the dynamical; then by particular ones of both we can express in terms of M, X, Y, Z, T, and *one selected quantity*, the dimensions of all the other relations. The only useful cases, however, are those in which the selected quantities are either μ or K, for these express physical properties of the medium at a point, and are independent of the electromagnetic reactions going on there. The dimensions in terms of μ are obtained by starting with the relation, $\mu . H^2 =$ energy per unit-volume; and similarly for the dimensions in terms of K.

Since the dimensions have to be deduced by means of a connected system of equations, it becomes necessary to make choice of suitable axes. Let X be the axis of electrical displacement and Y that of magnetic: they are mutually at right angles, and Z is at right angles to both, being the intersection of the electric and magnetic equipotential surfaces.

Let this relation hold good for every point of the medium, so that the axes constitute an instantaneous system at every point.

In passing, therefore, from point to point in the medium and for different epochs at the same point, the axes and the displacements preserve their relative directions, while their absolute direction in space, in general, alters.

In Fig. 368, let AO' be a closed electric circuit and BO a corresponding closed magnetic circuit, both being circles in planes at right angles to each other. Taking instantaneous axes, every element of the circuit AO' is δx and of the circuit BO is δy, while an element of the intersection of the planes of the circuits is δz. The length of the circuit AO' is $\Sigma\delta x$ and of the circuit BO, $\Sigma\delta y$, while the surfaces of the circuits are $\Sigma(\delta x\delta y)$ and $\Sigma(\delta y\delta z)$. We have, therefore:

$$\text{Circuitation } H = \Sigma(H\delta y) = C; \quad . \quad . \quad (95)$$

$$\text{Circuitation } E = \Sigma(E\delta x) = E; \quad . \quad . \quad (96)$$

$$\text{Surface integral of } D = \Sigma(D\delta y\delta z) = e; \quad . \quad . \quad (97)$$

$$\text{Surface integral of } B = \Sigma(B\delta x\delta z) = m. \quad . \quad . \quad (98)$$

To express these dimensionally, we have to neglect the summation sign Σ, and substitute for δx, δy, δz; X, Y, Z respectively: and then the magnetical relations in L.M.T. are deduced; and from them both the electromagnetic and the electrostatic systems are derived in dimensions L.M.T., and these equations are then mutually convertible by substituting the value of μ for K, and the converse.

The energy of the medium at any point may be expressed by $\Sigma m\ (X^2 + Y^2 + Z^2) = \Sigma(mr^2)$, where r is the instantaneous linear displacement upon which both the electric and the magnetic displacements at that point depend; for the two laws of circuitation express that these are not separate but originate from the same dynamical cause.

The force between two poles is in the direction of magnetization: the reason why it is expressed in terms of the energy of the system, is, that it is a mechanical force arising in some way from the mutual relation of matter and the medium. The quantities m and H in terms of which the force between the two poles is expressed, refer to the medium alone, and since nothing is known as to the relation between matter and the medium, the relation above expresses only the result-

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magnetic facts have been illustrated by those who have most deeply studied these from the dynamical point of view.

214. Light, Electricity, and Magnetism due to a movement of the Ether.—In the early inquiries into the nature of Light, it was considered an outcome of corpuscular matter shooting through space; Electricity, too, was material—two fluids; and Magnetism was an effluvium—either spirit or substance according to one's fancy: but gradually patient research forced upon the mind the conviction that Light was but a sensation due to motion—an undulation of an ethereal medium; further facts relating to Light literally cast a luminous beam upon Electricity and its congener Magnetism, discovering both to be due to a movement of the same ether—in fact, all three linked together in the same movement.

To these may be added Thermal and Chemical effects, for they produce the others, and those, these; so that, given any one, another, or all five of the effects—thermal, chemical, luminous, electrical, and magnetical—may be evoked from that one as an origin, and all as varied phases of the energy resident in ether-waves.

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